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VOLUME 32 MAY, 1952 No. 5

HYDROGEN CYANIDE AND METHYL BROMIDE AS FUMIGANTS FOR INSECT CONTROL IN EMPTY CARGO SHIPS[1]

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[Received for publication September 7, 1951]

INTRODUCTION

The problem of insect infestation in ships carrying cargoes of food from one part of the world to another has already been fully discussed by the senior author (14). In this publication a general description was given of the different control measures undertaken. It was stated that fumigation by means of a gaseous insecticide was necessary to secure satisfactory insect control when penetration was required into inaccessible sites of infestation. Among the most important of these sites were the spaces beneath the tank top ceilings and within the bilges. For the purpose of the present paper, the more important places are illustrated in Figure 1. An account (5) has also been given of the inspection and fumigation procedures in the port of Vancouver, B.C.

The present paper presents the results of an extensive study of the immediate and long term results of the use of the two fumigants, HCN and methyl bromide, which so far have been successfully applied to this type of work.

The only critical study found in the literature, on fumigation of insects in ships, is that of Williams (17) who found that for three species of cockroaches, *Blatella germanica* (L.), *Blatta orientalis* L., and *Periplaneta americana* (L.), a dosage of at least 8 ounces of HCN for an exposure period of 2 hours was required to kill all stages, including the eggs in the oötheca.

In practice, in many parts of the world, it has been customary to use HCN to control insect pests of foods in the holds of ships, at the rate of 8 to 12 ounces per 1,000 cubic feet for exposures up to 12 hours, without, apparently, much attention being paid to the effect of different temperatures. As long as the method was not subjected to an organized and detailed investigation, the success of the treatments could be judged only by an inspection of the cargo spaces immediately after fumigation and aeration. The presence of innumerable dead insects, and the apparent absence of living ones in the free spaces of the holds, indicated that the fumigation was a success. Because of the immediate need of loading the cargo, no oppor-

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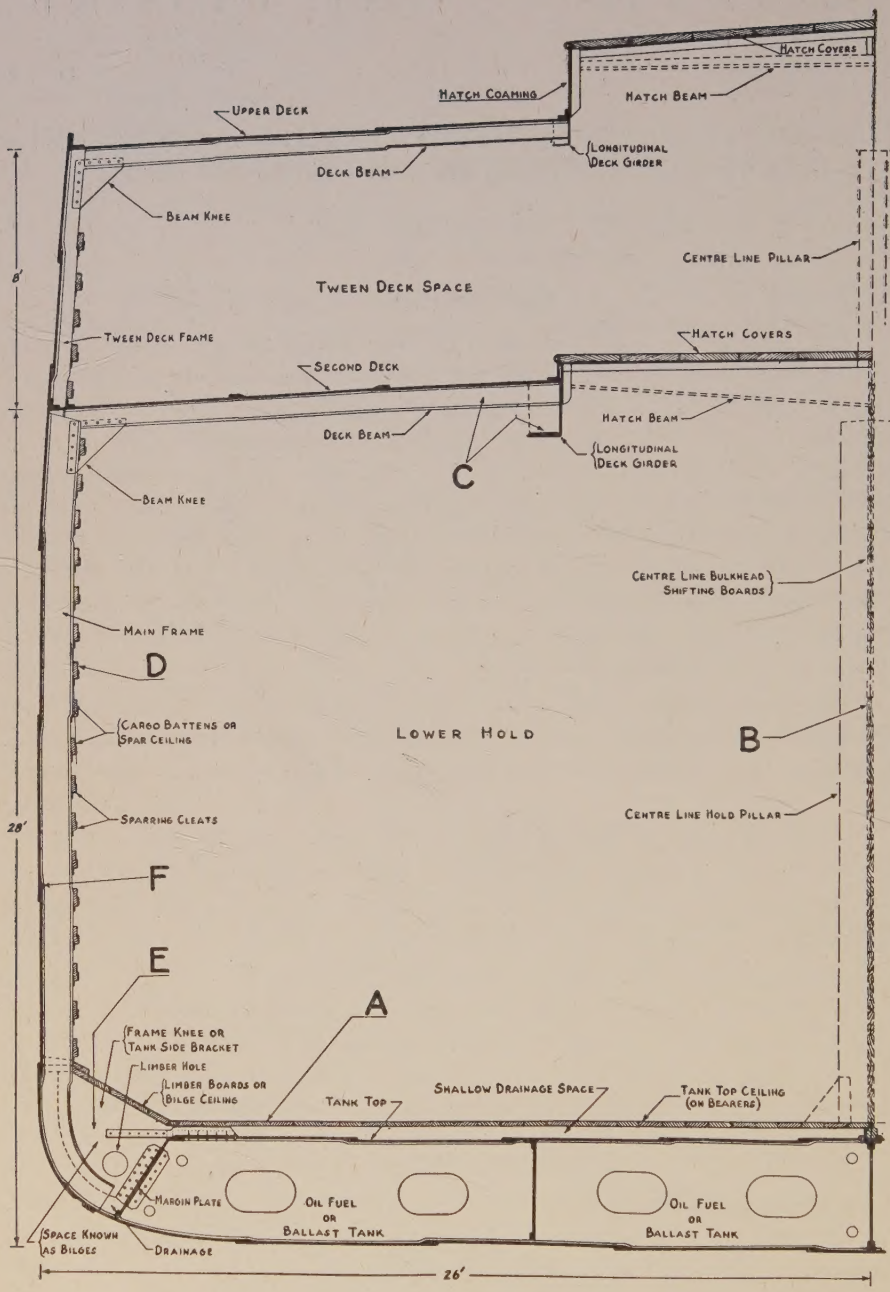

FIGURE 1. Midship section of a typical cargo space in an ocean-going ship

A Tank top ceiling
B Shifting boards
C Transverse beams, and longitudinal deck girders
D Spar ceiling
E Bilges
F Intersection of hull plates and frames

tunity would be afforded for a further check on the emergence of insects from inaccessible places or the development of immature stages within grain kernels. Thus, little was known about the ultimate results of these treatments if no re-infestation occurred.

The fumigation of one or more holds in a cargo ship to control insect pests is an expensive procedure. In addition to the charges for the fumigation itself, there must be added the cost of loss of time while the ship is tied up, and the outlay sometimes necessary for finding temporary accommodation for the crew. Moreover, there must be considered the possible hazards of this method, and the precautions taken to avoid them.

As far as is known to the writers, there has not previously existed any co-ordinated system for observations on the long-term results obtained. In Canada, beginning in 1947, opportunities were afforded for more thorough observations on the success of the treatments. A system was instituted for exchange of information between the ports on the east and west coasts, principally Halifax, N.S., Saint John, N.B., Montreal, Que., and Vancouver, B.C. It has thus been possible to determine the lasting effects of many of the treatments by inspections when the vessels have returned to the same or other Canadian ports.

It was soon apparent that although some of the fumigations with HCN on ships were completely successful, others had failed to reach the inaccessible sites already mentioned. Apart from difficulties encountered in obtaining satisfactory insect mortalities with HCN under certain circumstances, further problems were encountered during the post-fumigation period. During this process the persistent odour of HCN led to complaints from the stevedores and others working in the holds, although the concentrations of fumigant had been reduced by ventilation well below those of any toxicological importance. These problems are discussed more fully in the section "Considerations of Safety".

In view of these problems of insect control and human reaction, it was decided in 1948 to introduce methyl bromide as a ship fumigant, and to compare it with HCN under spring, summer, and fall conditions in Montreal, and during the winter in Vancouver.

THE MORE IMPORTANT INSECT SPECIES

From the records kept in Montreal during the last 10 years, it appears that there are about 60 species of insects and about 35 of mites that are common inhabitants of the cargo spaces of ships engaged in international trade. These insects and mites breed continuously in the holds of ships in the presence of sufficient food and under suitable conditions of temperature and humidity. Actually, only 21 species of insects have so far been regularly intercepted and these have been listed (14). Under normal conditions, only 13 species have developed populations sufficient to warrant extensive control measures, such as the fumigation or spraying of an entire hold. The

scientific and common names of these 13 species are given herewith in order to simplify the subsequent discussion under "Case Histories of Fumigated Ships":

Tenebroides mauritanicus (L.)	Cadelle
Tribolium castaneum (Hbst.)	Red flour beetle (rust-red beetle; bran bug; ship's ant)
Sitophilus oryza (L.)	Rice weevil (corn weevil; black weevil)
Sitophilus granarius (L.)	Granary weevil (grain weevil)
Laemophloeus spp.	Flat grain beetle and rusty grain beetle
Tribolium confusum Duv.	Confused flour beetle
Alphitobius diaperinus (Panz.) (*A. piceus* & *A. ovatus* of some authors)	Lesser mealworm
Pyralis farinalis (L.)	Meal moth (meal snout moth)
Oryzaephilus surinamensis (L.)	Saw-toothed grain beetle
Sitotroga cerealella (Oliv.)	Angoumois grain moth
Rhyzopertha dominica (F.)	Lesser grain borer (Australian wheat weevil; hooded grain borer)
Hofmannophila pseudospretella (Staint.)	Brown house moth (seed moth; false clothes moth)
Endrosis sarcitrella (L.)	White-shouldered house moth

PROPERTIES OF THE FUMIGANTS

The physical and chemical properties of HCN and methyl bromide are well known, and the bearing of these on ship fumigation has already been discussed in general terms (14).

A significant property of a fumigant gas is the degree to which it is sorbed at various sites, such as the interior surface of a building. It is obvious that there are two ways in which a fumigant may be retained by dry material, namely, by physical sorption or chemical reaction. The latter may be reversible or irreversible. If the sorption of the gas by the material, or by the walls of the fumigation space, varies inversely as the temperature, it is regarded as a physical phenomenon. If the loss of the fumigant to the surfaces of the material increases with the temperature, it is assumed that there is a chemical reaction.

Lubatti and Harrison (12) found, in a study of the sorption of a number of fumigants by wheat, that HCN was physically retained to a greater degree than methyl bromide, and that methyl bromide underwent a greater degree of chemical reaction. Subsequently Lubatti (11) defined the sorption of HCN by wheat as a largely physical phenomenon. Although Lubatti made no attempt to generalize from results obtained with wheat, it is clear from common practice that observations made under other conditions and with other materials can be explained by the same mechanism. For example, physical sorption is the cause of the difficulty of eliminating HCN from the interiors of ships undergoing fumigation during the winter months when, during the aeration process, the hatch covers are removed and cold air chills the interior surfaces. Part of the fumigant is then sorbed on the cold surfaces and cannot diffuse into the open air. Immediately the walls are warmed, the gas is desorbed and begins to diffuse into the open space.

The low degree of physical sorption of methyl bromide is demonstrated by the fact that it readily penetrates many commodities, sometimes at comparatively low temperatures (13).

If any of the surfaces being fumigated are damp, or if there is any water or other liquid freely exposed, the problem of loss of fumigant concentration by solution must be considered. Such solution may also delay the

post-fumigation aeration. As HCN is infinitely soluble in water and methyl bromide is only slightly so, greater difficulty will be encountered in eliminating the former from wet or moist holds of ships.

The reactions of the insects themselves to the two poisons may also be explained partly by differential sorption. For instance, Peters and Ganter (16) found that the granary weevil, *Sitophilus granarius* (L.), was more susceptible to HCN at 32° F. than at 63° F. However, these authors ascribed these results to differences in the physiological conditions of the insects at the two temperatures, and not to sorption. On the other hand, Carpenter and Moore (4) showed that the comparative resistance to HCN could be related to the amounts of the fumigant sorbed by each of several species of insects, and they also demonstrated that sorption of this gas was greater at 68° F. than at 80° F. Monro (14) has shown that methyl bromide functions efficiently against some species of insects at low temperatures, but increased dosages or exposure periods are required.

FUMIGANT DOSAGES

In the everyday commercial application of fumigants the dosages are expressed in pounds of fumigant per thousand cubic feet of space undergoing treatment. In laboratory work the concentrations obtained in the free space of the fumigant chamber are often expressed in terms of milligrams of fumigant per litre. While these two methods of expression are convenient for calculating and actually measuring the dosages of chemicals applied, they do not give a true basis for the scientific comparison of relative toxicities.

As a gas is an aggregation of individual molecules, each separated from its fellows and moving independently, the effect of the application of such a gas can only be truly expressed in terms of the total number of molecules employed. Thus, in a comparison between the same weight of two gases the heavier gas (that with the greater molecular weight) will be represented by fewer molecules. It is the individual molecules moving independently, but acting in unison, that add up to a certain total concentration required

TABLE 1.—AVERAGE RATE OF DEVELOPMENT OF *Sitophilus granarius* (L.) USED AS CONTROL SAMPLES, Montreal, QUE., AND VANCOUVER, B.C.

Time of year	No. of samples	Days between middle of oviposition period and emergence			No. of adults emerged	Origin of samples
		First Adult	Peak Emergence	Last Adult		
May, June, July, Aug., 1948	22	34.3	42.9	56.9	16,603	Montreal
Sept., Oct., 1948	7	35.6	48.2	64.9	4,639	Montreal
Nov., 1948	4	46.2	54.5	66.2	657	Samples shipped from Vancouver to Montreal
Dec., 1948, Jan., Feb., March, 1949	10	48.5	55.8	73.4	2,983	Samples shipped from Vancouver to Montreal
Total	43				24,882	

TABLE 2.—EXAMPLE OF METHOD OF RECORDING AND CALCULATING TEST INSECT MORTALITIES ON FUMIGATED SHIPS

Ship M5448, Hold No. 3. Dosage of CH_3Br 1 lb. per 1,000 cu. ft., temperature range 50–58° F., relative humidity 50%, exposure period 12 hours. No fan circulation employed. In each entry the top figure (*in brackets*) gives the number of survivors in each sample, the bottom figure the percentage mortality.

Position of Container in Hold		Test Insects					
		Granary weevil			Cadelle		
		Eggs	Larval instar		Adults	Larvae	Adults
			1	2			
Top	Starboard side, on longitudinal deck girder, 4 feet from corner of hatch	(56) 80.7	(14) 6.7	(4) 69.2	(156) 9.3	(7) 30	(7) 30
Top	Starboard side, on deck beam at corner of after bulkhead and starboard side	(119) 59.0	(7) 53.3	(1) 92.3	(51) 27.1	(9) 10	(10) 0
Top	Port side, on deck beam at corner of forward bulkhead and port side	(290) 0	(12) 20.0	(4) 69.2	(75) 3.8	— —	— —
	Total mortality, top of hold	46.6	26.7	76.9	11.9	20	15
Mid	Starboard side, corner of forward bulkhead and starboard side, hanging 6 feet from deck head	(100) 65.5	(10) 33.3	(0) 100	(111) 19.0	(6) 40	(7) 30
Mid	Starboard side, hanging midway between deck and deck head 6 feet from after bulkhead	(22) 92.4	(1) 93.3	(1) 92.3	(163) 3.5	— —	— —
Mid	Port side, hanging midway between deck and deck head, 6 feet from after bulkhead	(61) 78.9	(2) 86.7	(0) 100	(100) 0	(10) 0	(10) 0
Mid	Port side, hanging 6 feet in free air from deckhead	(270) 6.9	(12) 20.0	(7) 46.1	(100) 0	— —	— —
	Total mortality, mid-hold	60.9	58.3	84.6	6.3	20	18.2
Bottom	Starboard side, in bilges 10 feet from forward bulkhead	(0) 100	(0) 100	(0) 100	(0) 100	— —	— —
Bottom	Port side, in bilges 3 feet from after bulkhead	(1) 99.7	(0) 100	(0) 100	(0) 100	— —	— —
Bottom	Port side, in bilges 10 feet from forward bulkhead	(4) 98.6	(4) 73.3	(0) 100	(0) 100	(0) 100	(0) 100
	Total mortality, bottom of hold	99.4	91.1	100	100	100	100
	Mortality for entire hold	68.2	58.6	86.9	34.9	36	32

TABLE 3.—SUMMARY OF SHIP FUMIGATION TESTS

Test insects: Life stages of the granary weevil, *Sitophilus granarius* (L.)

In each entry for the mortality data the top figure gives the total number of survivors from each collection of samples, the middle figure (*in brackets*) the estimated original population, the bottom figure the percentage mortality. The exposure periods varied from 10–12 hours.

Period	No. of ships fumigated	Dose, lb. per 1,000 cu. ft.	Temp. range °F.	Relative humidity %	Mortality Data						
					Egg	Larval instar 1	Larval instar 2	Larval instar 3	Larval instar 4	Pupa	Adult
MONTREAL FUMIGATIONS, NAVIGATION SEASON 1948											
HCN											
May 11–June 6	5	.5 – .65	50 – 73	45 – 47	3,243 *(9,788)* **66.87**	351 *(76,419)* **99.54**	234 *(21,046)* **98.89**	340 *(9,584)* **96.45**	912 *(9,089)* **89.97**	302 *(2,703)* **88.83**	1,163 *(3,718)* **68.72**
METHYL BROMIDE[1]											
June 9–Oct. 31	12	.5 – 1.0	43 – 83	47 – 87	33 *(21,573)* **99.85****	31 *(33,280)* **99.91****	15 *(28,407)* **99.95****	78 *(35,552)* **99.78****	107 *(15,805)* **99.32****	7 *(4,410)* **99.84****	0 *(6,400)* **100****
WINTER FUMIGATIONS, VANCOUVER, 1948–49–50											
HCN											
Nov. 9–April 4	12	.5 – .75	37 – 57	60 – 100	176 *(7,872)* **97.76**	6 *(9,270)* **99.94**	66 *(5,089)* **98.70**	72 *(6,484)* **98.89**	672 *(6,284)* **89.31**	0 *(28)*[2] **100**	1,051 *(3,012)* **65.11**
METHYL BROMIDE											
Nov. 6–April 4	16	1.0 – 2.0	29 – 57	45 – 100	8 *(20,078)* **99.96****	5 *(15,285)* **99.97**	14 *(7,926)* **99.82****	56 *(11,190)* **99.50****	1,106 *(13,898)* **92.04****	267 *(1,171)*[2] **77.20**	435 *(8,375)* **94.81****

** Highly significant difference, from values of *t*, between mortalities for the two fumigants during the same season against the same stage of the insect. The asterisks are placed against the percentage mortality figure for the more effective fumigant in each instance.

[1] Not including two ships fumigated without fan circulation, see Table 6.

[2] Pupae exposed to HCN on one ship only and numbers too small for valid comparison with methyl bromide.

to produce a given effect. The number of molecules is expressed in terms of moles, or gram-molecules, obtained by dividing a given weight of gas by the molecular weight. This is expressed in metric units, and in order to facilitate comparison it is advisable to avoid low decimal numbers and to multiply the figure obtained for gram-molecules by the factor 10^6 and thus express the concentration in millionths of a gram-molecule per litre, or micromoles (μ moles) per litre.

In comparing the two fumigants under discussion, the dosage range of HCN lay between .5 and .75 pounds per thousand cubic feet; the molecular weight of this compound is 27.03; thus, after conversion to metric units, these dosages would be respectively 296 and 444 micromoles per litre. The dosages of methyl bromide applied ranged from .5 to 2.0 pounds per thousand cubic feet; the molecular weight is 94.95; these dosages, in turn, would be 84 and 337 micromoles per litre.

In reports of work with human and mammalian toxicology the gas concentrations are usually expressed in terms of volumes, either as parts per million or percentages. These expressions do give a correct picture as they take into account the number of molecules concerned as, by Avogadro's hypothesis, equal volumes of gases contain the same number of molecules. By definition, at 0° C. and 760 mm. pressure the weight in grams of 22.4 litres of a pure gas is the molecular weight of the substance. Thus the concentration in gram-molecules per litre can be converted into percentage volumes in air by multiplying by the factors 22.4 and 100 and adjusting for different absolute temperatures and pressures in the usual way. In the present paper the percentage volumes of the gases in air have been included in Tables 4, 5 and 7 in order to stress the different methods of expressing the concentrations.

Ferguson (6) and Ferguson and Pirie (7) have taken the molecular concept one stage further by suggesting the use of chemical potentials as indices of toxicity. These chemical potentials are expressions of the thermodynamic activity of molar concentrations of a gas at the site of the toxic action, or biophase, within a given organism. With gases, the value of the thermodynamic activity of a given molecular concentration is numerically equal to the relative saturation of the vapour at the biophase.

This theoretical discussion has been introduced to demonstrate that there are other and more revealing methods of expressing fumigant toxicities, and that comparisons based on simple weight in volume may be misleading.

The dosages of the two fumigants employed in the present study were selected on the basis of practicability of application. Insecticidal efficiency had to be reconciled with safety. In considering safety, the most important factor was the time required to aerate the cargo spaces after the close of the fumigation exposure. Ideally, aeration was considered to be complete not only when all possible toxic concentrations were removed, but also when residual odours had been reduced to the point where no complaints were made by persons working in the holds.

TABLE 4.—COMPARISON OF THE TOXICITIES OF HCN AND METHYL BROMIDE TO MATURE LARVAE AND ADULTS OF *Sitophilus granarius* (L.) AND *Tenebroides mauritanicus* (L.) EXPOSED IN SHIP FUMIGATIONS DURING 1948, 1949, AND 1950 IN MONTREAL, QUE., AND VANCOUVER, B.C.

Exposure period 10–12 hours

Treatment Data

Fumigant	HCN	CH_3Br
Number of ships	5	9
Dosage range, lb. per 1,000 cu. ft.	.5 – .625	.5 – 2.0
Percentage of fumigant by volume in air	.719% – .839%	.208% – .764%
Temperature range degrees F.	37 – 73	37 – 83
Relative humidity range, per cent	45 – 100	50 – 100

Insect Mortalities

	HCN			CH_3Br		
	Number Exposed	Number Survived	Percentage Mortality	Number Exposed	Number Survived	Percentage Mortality
S. granarius Fourth instar Larvae	8,786	919	89.5	11,575	784	93.2**
Adults	2,838	1,294	54.4	5,024	0	100**
T. mauritanicus						
Mature larvae	316	0	100**	223	33	85.2
Adults	240	0	100**	271	58	78.6

** Highly significant difference, $t > 2.58$. The asterisks are placed against the percentage mortality figure for the more effective fumigant in each instance.

APPLICATION OF THE FUMIGANTS

In all the fumigations studied the work was carried out by professional fumigators working under the supervision of inspectors of the Division of Plant Protection.

The method of applying the two fumigants in ships has been fully described (14). In the fumigations tested in the present study, the HCN was evolved from disks of wood or paper pulp and, in Montreal, contained either 5 or 15 per cent pure chloropicrin. In the fumigations with HCN in Vancouver, no chloropicrin was added as a warning gas. No fan circulation was employed with HCN, as the contractors were not equipped with fans of the explosion-proof type. The lower explosive limit of HCN has been set at figures varying from 5.6 to 12.8 per cent volume concentration in air (2). Dosages of HCN of 10 and 16 ounces per 1,000 cubic feet are equivalent respectively to .90 and 1.6 per cent volume concentration in air. In spite of this, there is always the possibility of the occurrence,

especially at the time of gas release, of small pockets of explosive concentrations in the region of a fan. The dosage of HCN applied varied from 8 to 12 ounces per 1,000 cubic feet, for a 10- to 12-hour exposure. For the reasons discussed in this paper, no large increases in dosage were made at temperatures below 60° F.

With methyl bromide, the pure fumigant unmixed with warning gas was employed and was applied from cylinders. Circulating fans were used in most instances, but on three occasions could not be employed. The fans were turned on for 30 minutes after the application of the gas, and also for 30 minutes every 4 hours during the exposure period.

At first methyl bromide was used at the rate of only 8 ounces per 1,000 cubic feet, as it had yet to be shown that this gas could be easily removed from ship holds 40 or 50 feet deep. Aeration was rapid and, as will be shown later, satisfactory mortalities were obtained with many species of insects. However, complete control was not obtained with adults and larvae of the cadelle, *Tenebroides mauritanicus* (L.). The dosage was then increased to one pound with improved results and no aggravation of the aeration problem. The dosage of methyl bromide was later varied according to temperature in accordance with the following schedule:—

Temperature, degrees F., in air space of hold	Pounds of Methyl Bromide per 1,000 cu. ft.	Exposure Period, hours
60 and above	1	10
50 – 59	1	12
40 – 49	1.5	12
30 – 39	2	12

With this fumigant, additional sealing materials were used, such as tarpaper, special tarpaulins inpregnated with plastic, or three layers of canvas tarpaulin in good condition.

DETERMINATION OF EFFICIENCY

The investigation of the efficiencies of the two fumigants was conducted in two ways:

(a) By placing test insects in various sites in fumigated holds, to test distribution of the gas and its penetration in lethal quantities into various inaccessible places.

(b) By rigorous inspection immediately after fumigation, followed by detailed reinspection of suspected places at the time of subsequent visits of the vessels to Canadian ports.

USE OF TEST INSECTS IN SHIPS

Materials and Methods

Insect Species.—Two species of insects were selected for test purposes: the cadelle, *Tenebroides mauritanicus* (L.), and the granary weevil, *Sitophilus granarius* (L.). These species are common in ships, are of economic importance, can be easily manipulated in the laboratory, and have shown marked differences in their susceptibilities to the two fumigants.

Rearing.—The stage of the cadelle principally employed was the mature larva, presumed to be in the fourth instar. Back and Cotton (3) state that a fifth instar sometimes occurs under unfavourable conditions. The larvae were reared on a variety of materials until a diet of moist rolled oats was finally selected.

TABLE 5.—VERTICAL DISTRIBUTION OF MORTALITIES OF *Sitophilus granarius* (L.) IN SHIP HOLDS, VANCOUVER, FEBRUARY TO APRIL, 1950

Exposure period 10 – 12 hours

Treatment Data

Fumigant	HCN	CH_3Br
Dosage range, lb. per 1,000 cu. ft.	.625 – .75	1.5 – 2.0
Percentage of fumigant by volume in air	.872% – 1.005%	.588% – .764%
Temperature range, degrees F.	37 – 57	37 – 50
Relative humidity range, per cent	60 – 100	60 – 100

Percentage Mortalities

Distance in feet below upper deck level	HCN	CH_3Br	
	Means* for 5 ships, no fan circulation	Means for 5 ships, normal fan circulation	Ship V0649, with fans removed 30 min. after gas application
5	61.2	99.2	17
10	56.4	100	51
15	57.8	100	96
20	68.2	100	100
25	63.2	100	100
30	78.2	100	100
35	81.8	100	100
40	81.6	100	100
Mean	68.6	99.9	83.0

* No significant differences with HCN which could be related to the vertical distribution of the insects in the holds.

All stages of the granary weevil, i.e., eggs, four instars of larvae, pupae, and adults, were employed in the tests. Continuous cultures were maintained, with moistened No. 1 Manitoba wheat as the medium, in an incubator at 80° F. and 60 per cent relative humidity. Nearly every weekday, adults that had emerged from the kernels 8–10 days previously were used to start new cultures. They were placed in the grain and left 3 or 4 days to lay eggs. Thus, it was possible to estimate with some accuracy what stages of the insect were present in the samples of grain used in the tests. Furthermore, at the time of the fumigations the stages present in the various samples of wheat were accurately determined after staining a portion of the kernels with acid fuchsin, according to the technique of Frankenfeld (9).

Placing Test Insects.—Before fumigation the separate lots of grain known to contain a certain immature stage of the weevil were shaken together so as to provide a uniform sample. The grain was then weighed out into 100-gram lots and placed in light cotton mailing bags, or salve tins screened top and bottom with 28-mesh brass screen. Adult granary weevils approximately 2 weeks old and mature larvae or adults of the

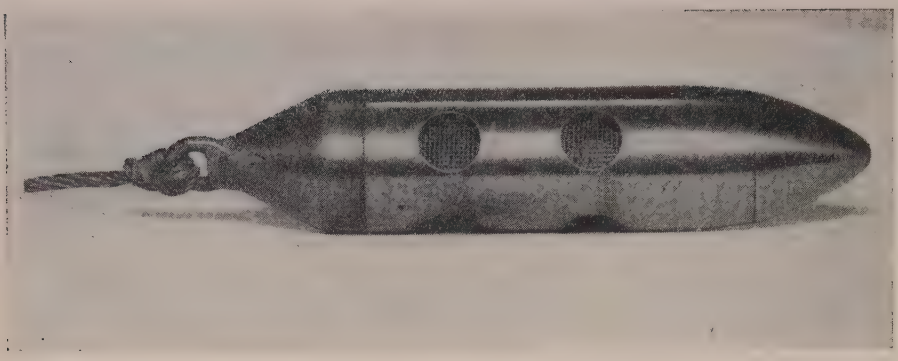

FIGURE 2. 20-mm. anti-aircraft shell modified as a capsule for containing test insects (natural size).

cadelle were placed with some grains of wheat in specially designed capsules (Figure 2) made from war-surplus 20-mm. anti-aircraft shells. Each capsule, lined with brass screening of 40 mesh to the inch, was fitted with a tapered base and ring, to which a cord or wire could be attached. The fumigant was diffused into the interior through 8 holes of five-sixteenths of an inch in diameter.

The various containers with the test insects were secreted in different recesses in the holds, such as inside the bilges or under broken floor boards, or were hung at varying levels between the tank top ceilings and the hatch covers.

At the same time a series of controls was made up to correspond to the stages placed under test. These were taken to the ships, but not placed in the holds.

In the winter months at Vancouver the test insects were carried to the ships from heated premises. In laboratory tests it was shown that the entire contents of the test containers in all cases reached the temperature of the surrounding air within 1 to $1\frac{1}{4}$ hours when removed from an atmosphere of 70° F. and placed directly in a temperature of 60, 50, 40, 30, or 20° F. As there was always an interval between the placing of the test insects and the application of the gas it may be assumed that the test material was at the same temperatures as the atmosphere of the fumigated hold during the greater part of the exposure period.

Post-fumigation Incubation.—After fumigation and aeration were completed, the test material was removed from the ships and returned to the laboratory. At Vancouver, mortality counts of adults of the granary weevil and adults and larvae of the cadelle were made in that city, but the treated and control samples containing the immature stages of the granary weevil were shipped by railway express to Montreal for incubation and mortality determination. The samples were incubated at 80° F. and 60 per cent relative humidity, and were sifted twice a week to remove emerging adults. This was continued until it was clear that the surviving insects had developed to the adult stage. Data on the average rate of development of the granary weevil observed under the above conditions of handling are summarized in Table 1.

TABLE 6.—THE EFFECT OF FAN CIRCULATION OF METHYL BROMIDE ON THE MORTALITY OF *Sitophilus granarius* (L.) USED IN SHIP FUMIGATION TESTS

Method of notation as in Table 3. Exposure period 10–12 hours.

Date	No. of ships fumigated	Dose, lb. per 1,000 cu. ft.	Temp. range °F.	Relative humidity %	Mortality Data							Remarks
					Egg	Larval instar				Pupa	Adult	
						1	2	3	4			
Sept. 27, 1948	1	1	68 – 72	45	13 (*11,720*) **99.9**	54 (*17,528*) **99.7**	24 (*71,280*) **99.9**	102 (*680*) **85.0**	418 (*3,056*) **86.3**	— — —	0 (*800*) **100**	Ship M4748. No fan circulation at any time during fumigation. Montreal.
Nov. 6, 1948	1	1	50 – 58	50	923 (*2,900*) **68.2**	62 (*150*) **58.6**	17 (*130*) **86.9**	— — —	— — —	— — —	756 (*1,161*) **34.9**	Ship M5448. No fan circulation at any time during fumigation. Montreal. See also Table 2.
Feb. 19, 1950	1	1.5	40 – 42	75	40 (*108*) **62.9**	139 (*224*) **37**	168 (*528*) **68.1**	155 (*472*) **67.1**	142 (*280*) **49.3**	— — —	100 (*208*) **48.1**	Ship V0649. Fans removed from hold 30 minutes after application of gas. Vancouver. See also Table 5.
1948 – 1950	28	.5 – 2.0	29 – 83	47 – 100	41 (*41,651*) **99.9**	36 (*48,565*) **99.9**	29 (*36,333*) **99.9**	134 (*46,742*) **99.7**	1,213 (*29,703*) **95.9**	274 (*5,581*) **95.1**	435 (*14,775*) **97.1**	Total of all ships in which fan circulation was employed at regular intervals during fumigation. Montreal and Vancouver.

Computation of Mortalities.—The final counts of the mortality of the adult weevils and of the cadelle adults and larvae were taken on the third day after fumigation and corrected for the natural mortality in the controls by the formula of Abbott (1).

The mortalities of the immature stages of the weevil were calculated in the following way. From the knowledge of the average durations of the life stages and instars within the kernels, and the study of the stained materials, it was known what life stage, or larval instar, predominated in each parallel group of samples. The predominant stage was accepted as the one present. The total number of adults subsequently emerging from each control sample was taken as the potential population of the particular instar or life stage concerned in each of the corresponding fumigated samples. In each case the potential population thus estimated was compared with the number of adults actually emerging from the fumigated samples, and the percentage mortality was calculated according to the following formula, adapted from Abbot (1):

$$\frac{\text{Number of weevils emerging from control} - \text{Number of weevils emerging from treated sample}}{\text{Number of weevils emerging from control}} \times 100 = \frac{x - y}{x} \times 100 = \text{percentage mortality}$$

Results

The method of recording results on individual ships is shown fully in Table 2. Apart from these detailed figures the balance of the data obtained with test insects as presented in this paper consists of summaries based on results recorded in Montreal and Vancouver from the spring of 1948 to the spring of 1950. In order to indicate the large number of test insects used, especially of the immature stages of the granary weevil, the data are presented to show, for each stage or instar, the number of insects surviving, the calculated original population, and the percentage mortality. These summaries are justifiable because, under normal conditions, position in the hold was of no significance, the mortalities being evenly distributed throughout. Three exceptions, one of which is reported in Table 2, occurred with methyl bromide, and are discussed below in the paragraph dealing with lack of fan circulation. The results with test insects used during these exceptional fumigations are not included in Tables 3, 4, and 7, but are given in Table 6.

The difference between the efficiencies of the two fumigants as demonstrated by the percentage mortalities has, wherever necessary, been subjected to a statistical test of significance, by obtaining a value of t from an equation derived from Hoel (10); this is suitable for the comparison of percentages when large numbers of individuals are present.

In this instance

$$t = \frac{p_1 - p_2}{\sqrt{\frac{p_1 q_1}{n_1} + \frac{p_2 q_2}{n_2}}}$$

where p_1 and p_2 are the probabilities of occurrence of the two independent percentage mortalities, q_1 and q_2 are the probabilities that these will not occur, and n_1 and n_2 are the sample sizes from the populations of insects

concerned. For instance, comparing the effectiveness of HCN and methyl bromide (Table 3) against the eggs of *Sitophilus granarius* (L.) in Montreal during 1948, the following substitutions are made:

$$t = \frac{.9985 - .6687}{\sqrt{\frac{.9985 \times .0015}{21{,}573} + \frac{.6687 \times .3313}{9{,}788}}}$$

$$= 69.23$$

According to the table of Fisher and Yates (8) for the distribution of t at the 1% level, with a large or infinite number of degrees of freedom, $t = 2.58$, and the difference is highly significant.

Tests at Montreal, 1948.—In Montreal (Table 3) during the navigation season of 1948, 39 ships were fumigated, in whole or in part, 5 with HCN and 34 with methyl bromide. Of these, 19 were the subjects of study with test insects, 5 being fumigated with HCN and 14 with methyl bromide. Under spring and summer conditions HCN was effective against the larvae and the pupae of the granary weevil, but failed to produce satisfactory mortalities of the eggs or adults. On the basis of these tests and the fact that one ship (M1648) had to be re-fumigated, as described below, methyl bromide was tested in June. From Table 3, and from the case histories to be given later, it is clear that methyl bromide produced satisfactory mortalities of insects in ships and its use was continued under close observation. Under the conditions of the Montreal tests it is clear that methyl bromide was significantly more effective than HCN, at the dosages used, against all stages of the granary weevil.

Tests at Vancouver, Winters 1948–49 and 1949–50.—After the use of methyl bromide in Montreal, it was decided to test it under the cooler conditions likely to be encountered in Vancouver during the winter months (Table 3). Twenty-eight fumigations were selected for study, 12 with HCN and 16 with methyl bromide. Though HCN had previously been used at comparatively low temperatures, without attention to increase in dosage, it was known from previous experience in other problems (13) that if satisfactory results were to be obtained with methyl bromide a graduated increase in dosage would be required, along the lines of the schedule given above.

In these fumigations at lower temperatures, varying between 29° F. and 55° F., methyl bromide applied at various dosages was significantly more effective than HCN (applied with but little increase in dosage) against all stages of the granary weevil except the first instar larva. The validity of the data from the use of HCN against the pupal stage is in doubt, because it was obtained from a single sample on one ship and only a small number of test insects was employed.

Use of Tenebroides mauritanicus (L.).—Because of difficulties at first encountered in building up the population of this insect it was used on only a limited number of ships. The data obtained with mature larvae and adults of this insect are summarized in Table 4, and compared with the corresponding figures obtained on the same ships with the granary weevil. This table shows that under both summer and winter conditions HCN is

more effective against the larvae and adults of the cadelle than is methyl bromide. There is thus a complete reversal of the results with the granary weevil.

Vertical Distribution of Mortalities.—The statement has already been made that, from data collected under normal fumigating conditions, position in the hold had no influence on the distribution of mortalities. For further confirmation of this observation a special series of tests was run in Vancouver early in 1950. The regular capsules, each containing 50 adult granary weevils and a small amount of grain, were suspended at intervals of five feet from the upper deck level down to the bottom in holds undergoing fumigation with either of the two fumigants. The results are condensed in Table 5. For HCN the analysis of variance of the entire data reveals that there were no significant differences in the mortalities that could be attributed to levels in the vertical arrangement of the capsules.

ANALYSIS OF VARIANCE OF PERCENTAGE MORTALITIES (transformed by means of the angle transformation) OF WEEVILS DISTRIBUTED AT DIFFERENT LEVELS DURING HCN FUMIGATIONS. DATA OF TABLE 5.

Source of variation	Degrees of freedom	Sum of squares	Mean square	F Value	
				Found	Required for 5% point
Between ships	4	2,551.34	637.835		
Between levels	7	2,043.756	291.965	1.812	2.36
Error	28	4,512.614	161.164		
Total	39	9,107.710			

Not significant; F is below the 5% point.

With methyl bromide, when the normal procedure of fan circulation was followed, the mortalities were 100 per cent with the exception of one sample on one ship at the top of the hold which showed a mortality of 96 per cent, this result being responsible for the mean percentage of 99.2 shown at the 5-foot level. Therefore, under ordinary conditions of operation, there were no significant differences in the vertical distribution of mortalities. The special case of ship V0649 is discussed under the next heading.

These results support the statement already made about the distribution of mortalities, and are further justification for presenting only summarized data in this paper.

Lack of Fan Circulation with Methyl Bromide.—Owing to the lack of suitable electrical circuits, fan circulation was not employed in two ship fumigations in Montreal in 1948. In another treatment in Vancouver in February, 1950, the fans were removed from the hold 30 minutes after fumigant introduction, when only the initial circulation had been carried out. The results from these treatments are given in Table 6 and are compared with the total mortalities recorded under normal conditions.

Also, the data in Table 2, obtained on one of the two Montreal ships, M5448, show the lower mortalities toward the top of the holds when fan circulation is not used.

These observations demonstrate that fan circulation is essential in methyl bromide fumigations in ships, unless most elaborate measures are taken to distribute the fumigant by other means. It is noteworthy that this effect is especially apparent at lower temperatures, as shown by the two fumigations conducted on November 6, 1948, and February 19, 1950. In ship V0649 (Tables 5 and 6) the lower mortalities at the three top stations can be explained in either of two ways: (*a*) that in the half-hour period adequate distribution had not yet been obtained with the fans or (*b*) that the loss of concentration of the fumigant toward the top of the hold during the removal of the fans was not re-adjusted during the balance of the fumigation period. Either explanation emphasizes the need for proper distribution of methyl bromide.

CASE HISTORIES OF FUMIGATED SHIPS

Without exception, all parts of ships that received insecticidal treatments as required by the Canada Department of Agriculture underwent detailed post-fumigation examinations by inspectors of the Division of Plant Protection.

There is obviously an essential difference between the climatic conditions encountered by ships carrying grain and flour to northwest Europe from eastern and those from western Canadian ports. Voyages from the eastern ports, Montreal in summer and Halifax and Saint John in winter, to western European ports are comparatively brief and, except for two or three months of warm weather, are made under cool or cold conditions. Once an infestation has been eradicated in the ships that stay regularly in this run, the conditions are less favourable for the building up of populations from insects surviving the fumigations or introduced from outside.

From the west coast ports, such as Vancouver, the regular run for the grain and flour trade is to the British Isles via the Panama Canal. All the year round, therefore, a considerable part of each voyage is spent in the tropics, under favourable conditions for the multiplication of many species of insects.

From April 1, 1947 to March 31, 1950, 322 fumigations of empty ships were conducted in Canadian ports; the total space fumigated was 116,756,610 cubic feet. Of these, 113 were treated with HCN and 209 with methyl bromide.

Selected from these, a limited number of typical case histories are included here to demonstrate some of the long-term effects of the fumigation treatments.

In studying and analysing the results presented in the case histories the assumption is made that Canadian northern (Manitoba) wheat was free from the pests discussed, particularly the granary weevil, *Sitophilus granarius* (L.). The senior author (14) has already dealt with this aspect of the problem and quotes the statement of Freeman and Turtle of the British Ministry of Food which reads, in part, "Manitoba wheat usually arrives in this country (Great Britain) entirely free from infestation or very slightly infested. It is exceptional to find a parcel infested by any of the major pests, e.g. *Calandra* (*Sitophilus*) sp. and when these are found their presence may usually be explained by the previous history of the ship,

the insects having been left behind from a previously infested cargo." For the most part, therefore, these case histories are those of ships engaged continuously, and usually without interruption, in the transportation of exported Canadian northern grain to ports in the British Isles or northern Europe. Ships engaged in this trade return to Canada with products not usually found infested with insects. Thus a reliable indication can be given of the success of the treatments on any particular species of insect.

The dosages of the fumigants, given in ounces or pounds avoirdupois, are the amounts per 1,000 cubic feet (abbreviated as M.) of hold space.

Ships Fumigated First with HCN

Ship V0348 (launched 1929) was inspected at Vancouver on November 17, 1948, and found infested with *Tribolium castaneum* and the European grain moth, *Nemapogon granella* (L.). Treatment was made with 10 oz. HCN per M. for 12 hr. exposure at 45–52° F. Inspection indicated a complete mortality, and the vessel was then loaded with Canadian wheat. This ship subsequently made 4 trips to and from the British Isles via the Panama Canal, loading Canadian grain at Vancouver each time (February 22, July 11, October 23, 1949, and February 26, 1950). There was no reappearance of these populations. This case affords a clear instance of the success of a fumigation with HCN at a comparatively low temperature.

Ship V1648 (launched 1930) was inspected at Vancouver on July 18, 1948, and found infested with *Sitophilus granarius* and *Sitotroga cerealella*. The holds were fumigated with HCN at 8 oz. per M. for 12.5 hr. at 64–70° F. A complete mortality was recorded and the ship was loaded with Canadian wheat. Subsequently 3 return voyages were made to Vancouver to load Canadian wheat (January 28, May 25, and September 11, 1949) and no infestations were found. However, on a fourth direct return to the same port (January 23, 1950) *S. granarius* had built up another population and fumigation with methyl bromide was required. The evidence suggests that HCN was not completely successful against the granary weevil, so that a large population was able to develop again within 18 months.

Ship M1648 (launched 1944) was inspected at Montreal on June 5, 1948, and found infested with *S. granarius, T. castaneum, Oryzaephilus surinamensis, Laemophloeus* sp., *S. cerealella, Rhyzopertha dominica, Sitophilus oryzae,* and *Tenebroides mauritanicus*. Treatment was with 8 oz. of HCN per M. for 13 hr. at 65–73° F. A complete mortality was recorded. The ship was loaded with wheat for European ports and returned to Montreal July 23, 1948, for Canadian wheat. At this time a few individuals of each of the above species were detected, but they were not present in large enough numbers to warrant treatment. On the next inspection in Montreal, on September 9, 1948, following a direct return voyage from northwest Europe, a severe infestation was found of each of the original species of insects, indicating that the results of the HCN fumigation were poor. On this occasion all holds were fumigated with methyl bromide at 1 lb. per M. for 10 hr. at 60–87° F. Two return visits were made to Montreal (November 2, 1948, and May 28, 1949), and no further infestations were found.

Ship V1748 (launched 1947) was inspected in Vancouver on April 27, 1948, and found infested with *S. granarius, T. castaneum, S. cerealella,* and *T. mauritanicus*. The holds were fumigated with HCN at 8 oz. per M. for 12 hr. at 54–59° F. Flour and grain were then loaded for the British Isles. On return of the ship to Vancouver on July 27, 1948, a population of *S. cerealella* was found in two holds. A spraying with a mixture of DDT and pyrethrum was requested. After one more voyage with grain to the British Isles, *S. granarius, T. mauritanicus,* and *Alphitobius diaperinus* were found in large numbers at Vancouver, on October 16, 1948. The ship was completely fumigated again with HCN at 10 oz. per M. for 11.5 hr. at 47–52° F. Grain was then carried to the British Isles and two return visits were made to Vancouver (January 27 and April 18, 1949), and both times the ship was found free of insect pests and loaded with Canadian grain. However, on a third return (September 9, 1949) *T. mauritanicus* was found infesting one hold only. Nevertheless, the captain requested all holds to be fumigated. Methyl bromide was used at 1 lb. per M. for 10 hr. at 65° F. Three return voyages were made (December 28, 1949, April 14, 1950, and February 13, 1951) with no sign of infestation.

In this ship HCN was not completely successful in dealing with the insect populations.

Ship V1848 (launched 1928) was inspected in Vancouver on November 14, 1947, and one hold was found infested with *S. granarius* and the Indian Meal moth, *Plodia interpunctella* (Hbn.). This hold was fumigated with HCN at 8 oz. per M. for 10 hr. After inspection, complete mortality was presumed. This ship loaded Canadian flour for the British Isles and returned to Vancouver on April 4, 1948, when it was found necessary to fumigate the same hold against *S. granarius*. This time methyl bromide was used at 1.25 lb. per M. for 10 hr. at 47–56° F. Wheat and flour were then loaded for the British Isles. This vessel returned to Vancouver on July 28 and October 3, 1949, and was found to be insect-free. However, when the ship was in Vancouver again on December 23 of the same year, *S. granarius* alone appeared in the same hold and fumigation with methyl bromide was required once again. This ship returned to Vancouver 3 times during 1950, with no further sign of the infestation. Clearly, HCN failed on this ship, but neither was methyl bromide wholly successful.

Ship V1948 (launched 1944) was inspected in Vancouver on January 12, 1948, and three holds were found infested with *S. granarius* and *O. surinamensis*. The holds were fumigated with HCN at 10 oz. per M. for 12 hr. Inspection indicated a satisfactory mortality and the ship was loaded with Canadian grain. However when the ship returned from the British Isles for another load, these two insects were again very numerous in two of the original holds and fumigation had to be repeated.

Ships Fumigated First with Methyl Bromide

Ship M1948 (launched 1933) was inspected in Montreal on June 10, 1948, and was found infested with the white-shouldered house moth, *Endrosis sarcitrella*. Methyl bromide was used at 8 oz. per M. for 12 hr. at 55–62° F. This ship subsequently carried Canadian grain from eastern Canadian ports in 15 voyages to northwest Europe; during this time no further living insects were found.

This is an instance of how insect populations may be eradicated and the holds remain clear as long as insect-free grain is carried.

Ship M1748 (launched 1940) was inspected in Montreal on June 8, 1948, and found infested with larvae of *Hofmannophila pseudospretella*. Methyl bromide was applied at 8 oz. per M. for 12 hr. at 54–59° F. A complete mortality was recorded, and this ship was still insect-free during the years of 1948, 1949, and 1950, during which she made 14 return trips between eastern Canadian ports and the British Isles, carrying Canadian grain. This case is similar to the preceding.

Ship M2048 (launched 1937) was inspected in Montreal on June 14, 1948, and one hold was found infested with *S. granarius*. Methyl bromide was used at 8 oz. per M. for 12 hr. at 59–66° F. This ship subsequently made 15 return voyages from eastern Canadian ports to the British Isles with cargoes of wheat and flour without the finding of any living insects of any economic species in this hold.

This case is remarkable for the effectiveness of a low dose of methyl bromide against this species.

Ship M2648 (launched 1930) was inspected in Montreal on July 8, 1948, and was found densely populated with *T. castaneum*, *T. mauritanicus*, *A. diaperinus*, and the almond moth, *Ephestia cautella* (Walk.). All holds were fumigated with methyl bromide at 1 lb. per M. for 12 hr. at 68–74° F. The ship was then loaded with Canadian grain for Belgium. Twenty-two months later she arrived in Vancouver on May 26, 1950, with a cargo of sugar from the Fiji Islands. At this time the ship was found to be clear of infestation.

Ship M5148 (launched 1946) was inspected in Montreal on October 2, 1948, and found heavily infested with *O. surinamensis*, *Laemophloeus* sp., *E. cautella*, and the foreign grain beetle, *Ahasverus advena* (Waltl.). All holds were fumigated with methyl bromide at 1 lb. per M. for 11.5 hr. at 47–62° F. After this treatment 14 return voyages were made to the British West Indies with cargoes of Canadian flour. The ship was inspected regularly at the Canadian ports, and no infestation was found until the fourteenth return to Halifax on January 20, 1950. At this time a cargo of cocoa beans slightly infested with *Ephestia* sp. was carried in one hold and after unloading, the residual population was removed by physical cleaning.

Ship M4448 (launched 1945) was inspected in Montreal on October 26, 1948, and one hold was found to contain large numbers of *Pyralis farinalis* and *A. diaperinus*. Treatment was made with 1 lb. methyl bromide per M. for 12 hr. at 43–52° F. A complete mortality was recorded. Twelve voyages were made to Belgium and the British Isles during 1948, 1949, and 1950 with no recurrence of infestation.

Ship M5448 (launched 1946) was inspected in Montreal on November 6, 1948, and was found densely populated with *P. farinalis*. Fumigation was made with methyl bromide at 1 lb. per M. for 12 hr. at 50–58° F. Twenty cargoes of Canadian flour and wheat were carried during 1949 and 1950 from eastern Canadian ports to Europe without the subsequent finding of any insect.

Ship V1548 (launched 1942) was inspected in Vancouver on August 14, 1949, and all holds were found infested with *S. granarius*, *Tribolium confusum*, and *A. diaperinus*. Fumigation was made with methyl bromide at 1 lb. per M. for 10 hr. at 71° F. Wheat was then loaded for the British Isles. Subsequent return voyages were made to Vancouver and inspections made on January 20 and June 17, 1950. No recurrence of the infestation was observed. Methyl bromide was thus completely successful against these insects.

Ship V1448 (launched 1918) was inspected in Vancouver on April 3, 1949, and found heavily populated with *S. oryzae* and *O. surinamensis*. The ship was fumigated with methyl bromide at 1 lb. per M. for 12 hr. at 41–53° F. Wheat for the British Isles was loaded and the ship came to Montreal for three successive cargoes of Canadian grain on June 10, July 13, and August 17, 1949. On all three occasions she was found to be clear of insects. Early in 1950 this ship carried barley from North Africa to a European port, and on returning to Three Rivers near Montreal on June 26, 1950, a severe infestation of several species of insects was found, but not including *S. oryzae*.

This case is an example of how a ship may remain clear of infestation after treatment as long as insect-free grain is carried, and of how infestation can be picked up in the ports of warmer countries.

Discussion of Case Histories

The long-term study of the results of ship fumigations is a very useful one; its value will increase with time. Already, enough information has been collected for some general conclusions to be drawn.

The limited number of case histories presented show that both compounds must be considered efficient for ship fumigation; in several instances they were remarkably successful in eliminating the insect populations. Therefore, a fumigation properly conducted with either of them must be considered a worth-while procedure, in both immediate and long-term effects. The greater effectiveness of methyl bromide against all stages of the granary weevil as demonstrated with the test insects was borne out by the case histories, as partial failure of HCN against this insect occurred more often than with methyl bromide. With some other species of insects, evidence in favour of methyl bromide must be offset by the fact that this fumigant afforded some of its most enduring results against lepidopterous larvae on board ships engaged in the North Atlantic trade, where a cooler climate prevails for most of the year and conditions are not as favourable for the re-establishment of infestations from possible survivors.

A side product of this study was confirmation of the assumption, already made, that Canadian hard wheat was free from infestation when exported under normal peace-time conditions. The record of conditions in numerous cargoes of Canadian grain after only one fumigation of a given ship emphasizes both the effectiveness of the treatment and the insect-free condition of the grain. Also, the history of ship M5148 is indicative that shipments of Canadian flour may retain a record of freedom from infestation, even when the shipments are made to the West Indies under conditions favouring insect multiplication.

CONSIDERATIONS OF SAFETY

Hydrocyanic Acid Gas

One of the reasons for the trial of methyl bromide in ship fumigation lay in the number of complaints that had been received from stevedores and others working in the holds after fumigation with HCN. Low concentrations of HCN, with or without chloropicrin as a warning agent, have an unmistakable odour which persists in the damp recesses of the holds and in the vicinity of woodwork for some time after the space has been declared fit to enter for working purposes. In the winter-time, following fumigations at lower temperatures, the release of the fumigant from the surfaces of the walls and structures in the holds was even slower, for reasons already discussed. Stevedores and others working in the holds are thus constantly reminded that a fumigation has taken place. As these men are not usually familiar with the properties of this fumigant, they sometimes exhibit a hysterical condition, with complaints of a variety of symptoms. On occasions the men have left work and gone home. These psychological complaints are difficult to deal with, especially as there may be some doubt at first as to whether a real case of poisoning has developed or not. Nevertheless, it must be emphasized that, since the beginning of the ship fumigation work in Vancouver in 1947 and in Montreal in 1948, there has been no case of HCN poisoning recognized as such by a physician. However, in view of the persistence of the residual odour, it was deemed inadvisable to increase the dosage above 12 oz. per 1,000 cubic feet under either summer or winter conditions.

When it was decided to test methyl bromide for this work there was some doubt whether the gas, which is $3\frac{1}{4}$ times as heavy as air, could be quickly and safely aerated from the holds. At first only 8 ounces per 1,000 cubic feet were employed. Under summer conditions, this concentration could be completely ventilated within 2 or 3 hours. Subsequent increase of the dosage to 1 pound was accomplished without encountering any difficulty in final ventilation, but it was found necessary in some cases to increase the aeration period from 4 to 6 hours, according to weather conditions. To expedite aeration, blowers have been introduced. These blowers should have an effective capacity of at least 4,000 cubic feet of air per minute; they perform better if used to blow air *into* the hold through a long canvas duct which is automatically inflated by the air pressure. The use of these blowers has already been described and illustrated (14). Later, under cooler conditions in the fall and spring in Montreal and during the winter in Vancouver, it was found necessary to increase the dosage to as much as 2 pounds of methyl bromide per 1,000 cubic feet. With the aid of blowers, and the fans normally placed in the holds for gas circulation, no problems of aeration have been encountered even under the most adverse conditions.

Pure methyl bromide is odourless, and under many conditions of fumigation it is advisable to add small amounts of a tear gas such as chloropicrin as a warning agent. However, in ship fumigation lack of residual odour in the pure, unmixed compound has proved to be an advantage. Once the holds have been declared gas-free by the fumigation operators it in nearly every case has proved impossible to detect any residual odour, and those entering the holds to work are usually quite unaware that a

fumigation has taken place. Consequently, there have been no hysterical complaints. In one or two exceptional cases, obnoxious odours emanating from piles of organic debris or pools of filthy water mixed with oil have been intensified as the result of the fumigation. This may have been due to a chemical reaction between methyl bromide and the organic material. Such spots were easily detected and eliminated.

Since the introduction of methyl bromide as a fumigant for empty ships in June, 1948, to date (January, 1951) there has been only one instance of suspected poisoning under normal fumigation conditions. The complainant, a member of a ship's crew, was dismissed from hospital within 8 hours of reporting sick; no further symptoms were reported.

The advantage imparted to ship fumigation by the odourless property of methyl bromide places a great responsibility on the fumigator. Before making his gas-free declaration he must make a careful check of all spaces in the ship to ensure that the fumigant has been properly ventilated.

DISCUSSION

For the reasons already given it was not deemed advisable to increase the dosage of HCN above 12 ounces per 1,000 cubic feet. On the other hand, it was found necessary, in order to maintain insecticidal efficiency, to increase the rate of methyl bromide to as much as 2 pounds. The question of various methods of expressing fumigant dosages has been fully discussed in a previous section, "Fumigant Dosages". Therefore, it must not be forgotten that the performances of these two fumigants are not being compared on the basis of equal dosage weights per thousand cubic feet.

The results obtained against *Sitophilus granarius* (L.) in all the ship fumigations tested in Montreal and Vancouver have been further condensed in Table 7. Excluded from this table are the data obtained on the three ships fumigated with methyl bromide without complete fan circulation (Table 5).

A significant fact shown in Table 7 is that, when the results are viewed as a whole, 100 per cent mortality was not produced by either of the gases against any stage of the insect. The highest mortalities produced by HCN and methyl bromide were 99.58 and 99.93 per cent respectively, both against the first-instar larvae. The senior author (15) has pointed out that such asymptotic results may be prophetic of the development of increased insect resistance to fumigants under field conditions.

Under the wide range of conditions encountered in these tests, in which large numbers of insects were employed, methyl bromide applied over a wider dosage range was more effective than HCN against all stages of *S. granarius*. An observation of interest is that the effectiveness of both compounds declined progressively as the insects developed through the larval instars and the pupal stage. In contrast to methyl bromide, the results with HCN against the adults were poor.

Under warmer conditions as experienced in Montreal between June 9 and October 3, 1948, methyl bromide was extremely efficient. Complete mortality of a large number of adults was obtained, and the high mortalities recorded with the other stages appear to be asymptotic.

TABLE 7.—SUMMARIES OF TREATMENT DATA AND OF MORTALITIES OF STAGES OF *Sitophilus granarius* (L.) EXPOSED IN SHIP FUMIGATIONS DURING 1948, 1949, AND 1950 IN MONTREAL, QUE., AND VANCOUVER, B.C.

Exposure period 10–12 hours

Treatment Data

Fumigant	HCN	CH_3Br
Number of ships	17	28
Total space fumigated, cu. ft.	2,605,761	7,535,603
Dosage range, lb. per 1000 cu. ft.	.5 – .75	.5 – 2.0
Percentage of fumigant by volume in air	.719% – 1.005%	.208% – .752%
Temp. range, degrees F.	37 – 73	29 – 83

Mortalities of *S. granarius*

	HCN			CH_3Br			
	Number Exposed	Number Survived	Percentage Mortality	Number Exposed	Number Survived	Percentage Mortality	Value of t
Egg	17,660	3,419	80.64	41,651	41	99.90**	64.70
1st larval instar	85,689	357	99.58	48,565	36	99.93**	13.92
2nd "	26,135	300	98.85	36,333	29	99.92**	15.85
3rd "	16,068	412	97.44	46,742	134	99.71**	18.32
4th "	15,373	1,584	89.70	29,703	1,213	95.92**	22.99
Pupa	2,731	302	88.94	5,581	274	95.09**	9.23
Adult	6,077	2,214	63.57	14,775	435	97.06**	43.97

** Highly significant difference, $t=2.58$ at 1% point for large numbers. The asterisks are placed against the percentage mortality figure for the fumigant more effective against the particular stage or instar.

A noteworthy result was that the effectiveness of HCN against the post-embryonic stages of the weevil did not vary greatly at high or low temperatures. It was considerably more effective against the eggs at low temperatures. These results can be seen in Table 3 by comparing the results in Montreal in 1948 against those obtained in Vancouver in the winters of 1948–49 and 1949–50. Though this difference may be largely influenced by temperature, atmospheric humidity cannot be ignored. In the HCN fumigations in Montreal in 1948, a relative humidity above 47 per cent was not recorded. Table 3 shows that the relative humidities recorded with HCN in the holds during the winter ranged from 60 to as high as 100 per cent. These results support the findings of other workers mentioned previously in the discussion of the properties of the fumigants. As has already been pointed out, the physical sorption of HCN on surfaces is greater than that of methyl bromide and it is also more soluble in water; both these effects are increased at low temperatures. Hence, the observations of Lubatti and Harrison (12) that relatively more HCN than methyl bromide is physically sorbed on wheat kernels are of interest when the possibility is considered of how the fumigant may be retained at low temperatures near the immature insects inside the individual grains.

Because of the difficulties at first encountered in building up the population of *Tenebroides mauritanicus* (L.), very few were available for field tests. Table 4 shows that under both summer and winter conditions HCN is more effective against the larvae and adults of the cadelle than is methyl bromide. This is a complete reversal of the results with the granary weevil. This striking difference in the susceptibilities of the two species of insects to the two fumigants is worthy of further investigation under laboratory conditions.

The comparative failure of methyl bromide against the cadelle as a test insect did not show up significantly in dealing with natural infestations of this species at dosages of one or more pounds per thousand cubic feet. The cadelle does not rank as high in economic importance as the granary weevil (14). In itself it is not responsible for large-scale outbreaks, although it is capable of inflicting severe damage by attacking the embryos of grains.

This work has demonstrated that a fumigation with HCN or methyl bromide, properly conducted, will result in satisfactory control of the insect pests in the holds. It has also shown that holds so treated may remain insect-free for considerable periods of time if non-infested material is carried and precautions are taken to prevent the introduction of fresh populations of pests.

SUMMARY

1. Methyl bromide was introduced as a fumigant for the treatment of the empty holds of ocean-going ships in Montreal in June, 1948. After this, under conditions of practical application in Montreal and Vancouver, a comparison was made between this fumigant and hydrocyanic acid gas on grounds of insecticidal efficiency, safety, and general suitability for ship fumigation.

2. It is pointed out that expression of fumigant dosage in pounds per thousand cubic feet, while convenient for measurement during practical application, does not provide a true basis for the comparison of the insecticidal efficiency of different gases. Comparison should be made in terms of the relative number of molecules employed, and this is provided by the expression of gas concentration as per cent by volume of the fumigant in air.

3. HCN was applied by the disk method, and methyl bromide under pressure from cylinders. Under the normal conditions of application of these two fumigants, effective insecticidal concentrations, as demonstrated by the placing of test insects, were evenly distributed throughout the holds. However, if no special means, such as circulating fans, were provided for the initial distribution of methyl bromide, this heavy gas settled in a layer at the bottom of the space.

4. For reasons of safety, the maximum dosage of HCN was limited to 12 ounces of fumigant per thousand cubic feet for a 12-hour exposure. Methyl bromide was applied at dosages of 8 ounces to 2 pounds per thousand cubic feet for 10 to 12 hours, according to temperature.

5. In the use of test insects, under normal conditions, methyl bromide was more effective against all stages of the granary weevil, *Sitophilus granarius* (L.). At temperatures below 60° F., HCN maintained its

effectiveness against all stages of this insect without increase of dosage, whereas it was necessary to increase that of methyl bromide to maintain its efficiency.

Under all conditions, HCN was more effective than methyl bromide against the cadelle, *Tenebroides mauritanicus* (L.), used as a test insect.

6. The long-term results of 15 ship fumigations, 6 originally made with HCN and 9 with methyl bromide, are discussed. This study reveals that each of these compounds, if properly applied, must be regarded as efficient for the purpose. The comparative failure of HCN against some stages of the granary weevil, demonstrated with the test insects, was also apparent against the natural populations of the same insect, which is an important pest in cargo ships.

Although methyl bromide was not so effective as HCN against the cadelle used as a test insect, this difference was not so apparent in dealing with natural infestations on the ships.

7. Each of the fumigants was successfully employed at low temperatures. The lowest temperature recorded with HCN was 37° F., with methyl bromide 29° F.

8. Although methyl bromide is a comparatively heavy gas, it was easily removed from the empty holds, especially with the aid of a blower.

9. Paradoxically, the lack of odour of methyl bromide, a serious handicap in many fields of fumigation, proved an advantage in ship treatments. After aeration, workers could enter the holds without anxiety; and psychological or hysterical manifestations, often encountered with HCN, were eliminated.

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THE EFFECTS OF VARIOUS GERMINATION TECHNIQUES TO OVERCOME DORMANCY IN GREEN STIPAGRASS SEED[1]

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INTRODUCTION

Green stipagrass is an improved variety of green speargrass *Stipa viridula* Trin., which was developed at the Northern Great Plains Field Station, Mandan, North Dakota (6). The variety appears to be well adapted to cultivation in southwestern Saskatchewan. This is understandable, since the species from which it was selected is a native of the area. According to limited yield data, green stipagrass has produced as well or better than crested wheatgrass or bromegrass. One of its attributes seems to be a lesser tendency to go into a sod-bound condition and hence greater production from three-year-old and older stands can be expected.

Considerable difficulty has been experienced in establishing green stipagrass because of its dormant seed characteristic. Although good stands have generally resulted at Swift Current, Saskatchewan, from fall seedings, spring seedings have given either poor or no stands. This failure to obtain stands can be traced directly to poor germinability of the seed. Freshly harvested seed seldom germinates over 20 per cent and often as low as 2 per cent.

This study was undertaken to determine methods of overcoming dormancy in green stipagrass and at the same time to study the causes of dormancy. The experiments were carried out in the laboratory and greenhouse.

LITERATURE REVIEW

Although several papers have been published dealing with treatments to improve germination in the related genus *Oryzopsis*, none was found by the authors which dealt specifically with the genus *Stipa* (2 and 3).

Huntamer (1), has shown a considerable variation in the seed viability of *Oryzopsis hymenoides* (Roem. & Schutt.) Ricker., collected from different sections of the State of Washington. When the seeds were treated with concentrated sulphuric acid to weaken the seed coats, satisfactory germination was obtained from most collections. She concluded that acid treatment performed the same function as mechanical scarification in removing the seed coats which were believed to be the cause of low germination.

Laude (4), reported improving stand establishment of Smilo grass, *Oryzopsis miliacea* (L) Benth. & Hook., by treating the seed with 71 per cent sulphuric acid for twenty minutes and sodium hypochlorite for 60 minutes. In a field trial only 3.8 per cent of the untreated seed emerged while 40.8 per cent of the seed treated with the acid emerged and 31.8 per cent treated with the salt emerged.

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[2] Graduate Assistant and Agricultural Research Officer, respectively.

Porter (5), recently reviewed a considerable amount of work on the developments of seed technology, with special attention to the advances in knowledge relating to impermeable and dormant seeds, including various germination techniques used to overcome dormancy. Several of these techniques were used in the present investigation.

Stoddart and Wilkinson (7), working with *Oryzopsis hymenoides*, found germination tests without seed treatment gave unsatisfactory results. Examination revealed that often over one-half the seeds lacked a developed embryo and hence could never germinate. Numerous mechanical and chemical tests to increase the germination of developed seeds indicated that the firm seed coats prohibited germination. Sulphuric acid, 72 per cent, was the most satisfactory method of increasing germination. The period of treatment varied with the size of the seed, very small seeds requiring from 15 to 45 minutes, but very large seeds from 60 to 120 minutes before dormancy was broken.

MATERIAL AND METHODS

The seed used for the study was harvested in 1950 at Swift Current, Saskatchewan, and the investigation was carried out about 4 months after harvest.

Repeated germination trials, by standard methods, gave a germination of 3 per cent. However, a potential gemination of 80 per cent was indicated by treatment with triphenyl tetrazolium bromide. This reagent has the capacity to differentiate between viable and non-viable seeds by a colour reaction when seeds are immersed in it (5).

All germination was carried out in the light at 25° C. on blotting paper pads fitted into Petri dishes; 100 seeds were used per treatment and each treatment was repeated twice.

In the sulphuric acid scarification treatment, dry seeds were immersed in the acid contained in a test tube and stirred to insure complete wetting. About 5cc. of acid was used for 100 seeds. After the specified treatment the seed was thoroughly washed in tap-water for 15 minutes before transferring the seed to germination pads.

In the pre-chilling treatment, the seeds were moistened and then held at a temperature of 4° C. for 3 weeks.

Two experiments were conducted. The results obtained in the first prompted the undertaking of the second.

Experiment 1—Seed Treatments Involving Pre-chilling and/or Chemical and Mechanical Methods

1. Check—no pre-germination treatment.
2. Seeds were moistened and then pre-chilled.
3. Seeds were moistened and then pin-pricked once.
4. Seeds were moistened, pin-pricked and then pre-chilled.
5. Seeds were soaked in absolute alcohol for 1 hour.
6. Seed coats were carefully removed from each seed.
7. Seed coats were carefully removed from each seed and then pre-chilled.
8. Seed coats were scarified by treating with concentrated (95 per cent) sulphuric acid for 2½ minutes. The seeds were then washed.
9. Seed oats were scarified by treating with concentrated (95 per cent) sulphuric acid for 2½ minutes. The seeds were then washed and pre-chilled.

Experiment 2—Sulphuric Acid Seed Treatments

The results from the first experiment indicated that the sulphuric acid treatment was the most successful in breaking the dormancy of green stipagrass seed. Consequently, the second experiment was undertaken, using various immersion time periods and two concentrations of acid.

Check—No pre-germination treatment.

Treated—Immersion in 95 per cent sulphuric acid.

A-1 2 minutes
A-2 3½ minutes
A-3 5 minutes
A-4 10 minutes
A-5 15 minutes

Treated—Immersion of seed in 72 per cent sulphuric acid.

B-1 20 minutes
B-2 40 minutes
B-3 60 minutes
B-4 80 minutes

RESULTS AND DISCUSSION

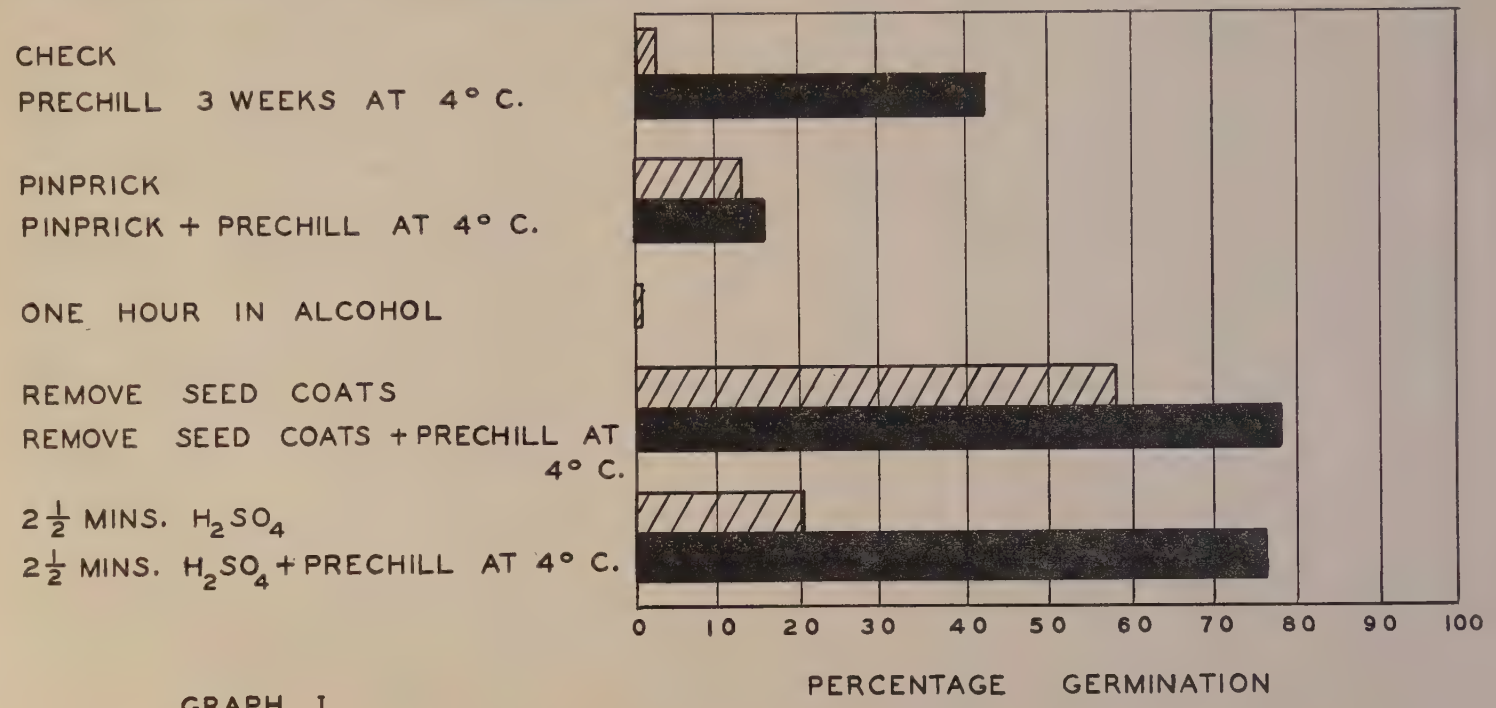
Experiment 1—Seed Treatments Involving Pre-chilling and/or Chemical and Mechanical Methods

The results from the effects of the various seed treatments on germinability of the seed are presented in Table 1 and Graph 1.

The data indicate that two kinds of dormancy must be manifest in green stipagrass seed. One kind is physiological which can be largely overcome by pre-chilling moistened seed prior to germination; and the other is mechanical, requiring a thorough breaking down of the seed coat before germination can take place. Removing the seed coat without any pre-chilling treatment induced more seeds to germinate than the pre-chilling treatment alone. (Compare treatment 2 and treatment 6 in Table 1). The removal of the seed coat, combined with a pre-chilling treatment, was equally effective in breaking down seed dormancy as scarification with 95 per cent sulphuric acid combined with a pre-chilling treatment. From the results it can be concluded that scarification of the

TABLE 1.—THE EFFECT OF VARIOUS PRE-GERMINATION TREATMENTS ON GERMINATION OF GREEN STIPAGRASS SEED

Treatment No.	Treatment prior to germination in light at 25° C.	Average percentage germination in 2 lots of 100 seeds after				Total per cent germination
		1 week	2 weeks	3 weeks	4 weeks	
1	Check—no treatment	0	1	1	0	2
2	Pre-chill 3 weeks at 4° C.	20	18	3	1	42
3	Pin-prick	4	3	3	2	12
4	Pin-prick, 3 weeks at 4° C.	8	6	1	0	15
5	One hour in alcohol	1	0	0	0	1
6	Remove seed coats	41	13	4	0	58
7	Remove seed coats, 3 weeks at 4° C.	71	3	1	0	78
8	2½ minutes H_2SO_4 (95 per cent)	4	14	2	0	20
9	2½ minutes H_2SO_4 (95 per cent) 3 weeks at 4° C.	51	18	7	0	76


PREGERMINATION SEED TREATMENTS
CHECK
PRECHILL 3 WEEKS AT 4° C.
PINPRICK
PINPRICK + PRECHILL AT 4° C.
ONE HOUR IN ALCOHOL
REMOVE SEED COATS
REMOVE SEED COATS + PRECHILL AT 4° C.
2½ MINS. H_2SO_4
2½ MINS. H_2SO_4 + PRECHILL AT 4° C.
0 10 20 30 40 50 60 70 80 90 100
PERCENTAGE GERMINATION

GRAPH I

seed coat, combined with pre-chilling moistened seed for three weeks, overcomes dormancy and brings germination of the seed to as high as the percentage of viable seeds indicated by the triphenyl tetrazolium bromide seed viability test.

The pin-pricking of seeds involving a single prick through the seed coat deep into the endosperm was not successful in increasing germination very significantly, possibly because of insufficient rupture of the seed coat to allow water imbibition. The lower germination of the seeds which were pin-pricked and pre-chilled, as compared with those which were pre-chilled only, could conceivably be due to injury to the embryo caused by the pin-pricking.

Seeds soaked in alcohol have often been reported to germinate better due to an increased permeability of the seed coat (5), but results indicate that with green stipagrass such treatment is ineffective.

Experiment 2—Sulphuric Acid Seed Treatments

The results from the various sulphuric acid treatments, without seed pre-chilling, are presented in Table 2.

TABLE 2.—THE EFFECT OF DIFFERENT SULPHURIC ACID SCARIFICATION TREATMENTS ON GERMINATION OF GREEN STIPAGRASS SEED

Treatment No.	Treatment	Per cent germination after				Total per cent germination
		1 week	2 weeks	3 weeks	4 weeks	
Check	No treatment	0	1	0	0	1
A-1	2 minutes in 95 per cent H_2SO_4	5	10	8	0	23
A-2	3½ minutes in 95 per cent H_2SO_4	20	7	4	3	34
A-3	5 minutes in 95 per cent H_2SO_4	27	3	4	1	35
A-4	10 minutes in 95 per cent H_2SO_4	36	11	10	1	58
A-5	15 minutes in 95 per cent H_2SO_4	11	0	0	0	11
B-1	20 minutes in 72 per cent H_2SO_4	6	4	2	3	15
B-2	40 minutes in 72 per cent H_2SO_4	12	12	5	1	30
B-3	60 minutes in 72 per cent H_2SO_4	17	13	3	0	33
B-4	80 minutes in 72 per cent H_2SO_4	16	12	3	1	32

The most effective scarification was obtained by immersing the seed in 95 per cent sulphuric acid for 10 minutes. A shorter immersion time in this acid did not accomplish complete scarification and a longer period (15 minutes) injured the seed.

Immersing the seed in 72 per cent sulphuric acid for longer periods did not accomplish complete scarification. Equally as good results were

obtained by immersing the seed in sulphuric acid for 40 minutes as when treated for 80 minutes. Thus, it would seem that seed cannot be readily injured in acid of 72 per cent concentration.

To achieve good scarification concentrated sulphuric acid (95 per cent) used with care would be most satisfactory.

SUMMARY

A standard germination test of green stipagrass seed indicated only 3 per cent germinability. However, triphenyl tetrazolium bromide indicated a potential germinability of 80 per cent.

Nine different techniques were used in attempting to break the dormancy of green stipagrass seed.

Pre-chilling moist seeds increased the germination in all cases; while sulphuric acid used as a scarifying agent increased germination by varying amounts, depending on both acid concentration and period of immersion.

The investigation suggests that green stipagrass seeds possibly exhibit both mechanical and physiological dormancy.

A possible practicable application could be developed from the above results. Spring sown seeds should be scarified with sulphuric acid or should be moistened and undergo a pre-chilling treatment.

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THE DIAMETER OF THE WHEAT STEM IN RELATION TO THE LENGTH AND SEX OF EMERGING SAWFLY[1] (*CEPHUS CINCTUS* NORT.)

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INTRODUCTION

In the investigations on the reaction of certain wheat varieties to sawfly attack both percentage cut and the characteristics of emerging populations have been studied (5, 6). It was shown that varieties differ markedly in the percentage of stems cut when exposed to sawfly attack. However, none of the varieties was immune to damage. In studies of residual populations from both susceptible and resistant varieties it was shown that the length of female varies with the variety and station. This is of interest because female length has been shown to be associated with the number of eggs oviposited. Larger females produced more eggs than smaller ones (2).

It is known that variety and amount of tillering influence the size of wheat stems (7). The possibility exists that the differences in length of sawfly may be due to the difference in the size of the stems in which they were reared. This study was undertaken to determine the relationship between the two.

In previous studies variety has been shown to affect sex ratios (6). Some varieties throw a preponderance of females, others a preponderance of males, and still others a normal ratio. As a result, the possible association between the size of stub and the sex ratio was examined in the present study.

METHODS

The method used for growing the material is given in detail in a previous publication (5). In brief, the varieties were grown in single-row plots, replicated five times, at three stations. They were exposed to a heavy infestation of sawflies. Twenty stubs from each of five replicates of six varieties at three stations were collected at random in the spring. Three lines, namely, S-633, H4137 and H4191, fall into the resistant group as judged by percentage cut, whereas the three varieties, Thatcher, Red Bobs and Garnet, belong to the susceptible group. Each stub was placed in a shell vial and kept at room temperature until emergence took place. The sex of each sawfly was noted. The length of the female sawfly was measured, and the outside diameter of the stub from which all sawflies emerged was taken. The measurements were taken by means of a vernier caliper.

It was originally intended to take the average readings from each replicate at each station and analyse the results by covariance. However, there was not sufficient emergence of females in all cases to allow for valid averages. Therefore, coefficients of correlation between female length and stub diameter were calculated for each variety using data from individual stubs in all replicates and all stations.

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The analysis of variance was used in determining variety and station differences in size of stub and length of female.

In comparing diameters of stubs from which the females emerged with diameter of stubs from which males emerged, all male-containing stubs and all female-containing stubs were averaged for each variety at each station. For this comparison "Students" method was used. In studying the relationship between diameter of stub and sex ratio, chi-squared tests of independence were used. Stem diameters were divided into two classes, large and small. The mode was used as the point of division.

RESULTS

The data on the length of the female from six varieties and three stations are presented in Table 1. The results show that the length of females varies according to the variety in which they are reared. Stations have little or no effect on the length of sawfly in this investigation.

TABLE 1.—AVERAGE LENGTH IN MILLIMETERS OF FEMALE TAKEN ON SIX VARIETIES AT THREE STATIONS

Variety	Swift Current	Scott	Shaunavon	Average Station
Thatcher	7.7	7.9	8.3	8.0
H4137	6.8	7.3	6.9	7.0
S-633	7.1	7.6	7.3	7.3
H4191	7.3	7.6	8.1	7.7
Red Bobs	7.8	8.3	8.3	8.1
Garnet	8.1	8.1	8.1	8.1
Average	7.5	7.8	7.8	
F 13.60			1% point 5.64	
S.E.M. 0.123				
Min. Sig. Diff. 0.4				

The data on the diameter of stubs from which the females emerged are presented in Table 2. The results show that the diameter of stub varies according to the variety. There were no significant differences between stations in stub diameters.

TABLE 2.—AVERAGE DIAMETER IN MILLIMETERS OF STUB FROM WHICH FEMALES EMERGED IN SIX VARIETIES AT THREE STATIONS

Variety	Swift Current	Scott	Shaunavon	Average Station
Thatcher	2.4	2.5	2.5	2.5
H4137	2.5	2.5	2.8	2.6
S-633	2.5	2.7	2.6	2.6
H4191	2.5	2.5	2.3	2.4
Red Bobs	2.8	2.9	3.1	2.9
Garnet	2.2	2.5	2.4	2.4
Average	2.5	2.6	2.6	
F 8.13			1% point 5.64	
S.E.M. 0.070				
Min. Sig. Diff. 0.2				

The coefficients of correlation between the length of females and the diameter of the stubs from which they emerge are presented in Table 3. In four varieties the correlation coefficient was highly significant, one was significant, and one was non-significant. Using the Z test significant differences between the correlation coefficients were established.

TABLE 3.—COEFFICIENTS OF CORRELATION BETWEEN LENGTH OF FEMALE AND STUB DIAMETER

Variety	n	r	z
H4191	61	0.473**	0.51
H4137	56	0.176	0.18
S-633	82	0.421**	0.45
Garnet	110	0.202*	0.20
Red Bobs	132	0.334**	0.35
Thatcher	107	0.337**	0.35

* Min. Sig. Diff. 5%
** Min. Sig. Diff. 1%
S.E.M. 0.27

The average width of stubs from which females emerged was 2.6 millimeters as compared with 2.4 millimeters for those from which the males emerged. The difference was statistically significant. The t value was 6.65 and the P value less than .01.

The observed and calculated numbers of male and female sawflies emerging from large and small stems are presented in Table 4. The chi-squared values that were calculated are shown. In all cases except two the chi-squared value deviates significantly from a 1 : 1 ratio. The data show that there was an excess of females emerging from large stems and a corresponding deficiency of males from such stems. Similarly, there was an excess of males and a deficiency of females from small stems.

DISCUSSION

The length of the female and consequently the fecundity are influenced within a variety by the size of the stem from which it develops. This was shown by the fact that in five of six varieties significant correlations were established. However, in no case was the value of r large. In fact less than 20 per cent of the variability in female length can be ascribed to stem size.

The number of varieties investigated was too small to establish differences between variety correlations. This relationship is being investigated in a separate experiment.

In comparing the diameter of small and large stems with sex of sawfly it was shown that females develop from stems of greater diameter than do males. McGinnis (4) compared main stems with tillers and found no difference in sex ratios. His results were taken on only two varieties for one year.

The chromosomal mechanism of sex determination in the sawfly is not well understood. Mackay (3) working with a limited number of individuals found the chromosomal conditions to be diploid in females and haploid in males. McGinnis (4) studied the progeny of unmated females and found

TABLE 4.—THE OBSERVED AND CALCULATED NUMBER OF MALE AND FEMALE SAWFLIES EMERGING FROM LARGE AND SMALL STEMS

Station	Sex of Sawfly	Size of Stub	Thatcher		Red Bobs		Garnet		H4191		H4137		S-633	
			Obs.	Cal.	Obs.	Cal.	Obs.	Cal.	Obs.	Cal.	Obs.	Cal.	Obs.	Cal.
Swift Current	Female	Large	24.0	20.6	25.0	22.0	21.0	19.8	10.0	5.8	9.0	6.9	21.0	15.1
		Small	16.0	19.4	15.0	18.0	14.0	15.2	5.0	9.2	3.0	5.1	5.0	10.9
	Male	Large	12.0	15.4	8.0	11.0	22.0	23.2	17.0	21.2	18.0	20.1	4.0	9.9
		Small	18.0	14.6	12.0	9.0	19.0	17.8	38.0	33.8	17.0	14.9	13.0	7.1
X^2				2.70*		2.73*		0.31*		6.29*		2.02*		13.93*
Scott	Female	Large	20.0	15.4	27.0	23.1	23.0	20.7	20.0	13.1	13.0	13.2	25.0	18.3
		Small	10.0	14.6	20.0	23.9	20.0	22.3	7.0	13.9	8.0	7.8	6.0	12.7
	Male	Large	20.0	24.6	4.0	7.9	15.0	17.3	17.0	23.9	9.0	8.8	8.0	14.7
		Small	28.0	23.4	12.0	8.1	21.0	18.7	32.0	25.1	5.0	5.2	17.0	10.3
X^2				4.60*		5.11*		1.08*		10.94*		0.20		13.39*
Shaunavon	Female	Large	25.0	15.8	33.0	26.3	22.0	17.1	12.0	8.8	17.0	8.9	19.0	11.1
		Small	9.0	18.2	11.0	17.7	8.0	12.9	6.0	9.2	5.0	3.1	6.0	13.9
	Male	Large	9.0	18.2	7.0	13.7	22.0	26.9	16.0	19.2	4.0	12.1	4.0	11.9
		Small	30.0	18.9	16.0	9.3	25.0	20.1	23.0	19.8	26.0	17.9	23.0	15.1
X^2				18.73*		12.34*		5.34*		3.32*		21.46*		19.48*

* Deviate significantly from a 1 : 1 ratio.

them to be almost entirely male. The occasional female may have been due to the progeny of an unreduced egg owing to the failure of reduction division in the oocyte.

The mechanism of sawfly fertilization is not understood. McGinnis (4) quotes the work of Brunson (1) in which he states that the hymenopterous parasite *Tiphia popilliavora* is capable of fertilizing eggs selectively at time of oviposition. It is possible that the sawfly has the same ability. McGinnis (4) postulates that the size of stem in which the female is ovipositing might be the stimulus for fertilization or non-fertilization. If this is correct it might be possible to explain differences in sex ratios among the progeny in sawflies reared in different varieties by differences in stem size between varieties. He was unable to substantiate this hypothesis in his investigation because of the abnormal mortality in the experiment.

The results of the present investigation lend support to McGinnis' (4) hypothesis as within each variety there was a preponderance of females in the larger stems and of males in the smaller ones. The number of varieties was too small to attempt to establish correlations between stem size and sex ratios. The results might also be explained by the following hypothesis. Smaller stems are usually later-maturing and in general would be those that were infested last. It is possible that the supply of spermatozoa might be insufficient to fertilize the late-deposited eggs. If this is correct one would expect an association between maturity of the variety and sex ratio. Early varieties would produce a preponderance of females and late varieties a preponderance of males. This possibility is being investigated in a separate experiment.

SUMMARY

The relationship between the length of female and the size of stub was studied in six different varieties, grown in five replicates, at three stations. A possible association between the size of stub and sex ratio was also examined. The length of female and the outside diameter of the stubs from which males and females emerged was measured by means of a vernier caliper. The sex was noted as each sawfly emerged. Varietal differences in length of emerging females and in stem diameter were established. Station differences were not significant. Correlation coefficients between length of sawfly and the diameter of the stub were very significant in four varieties, significant in one, and non-significant in one. Significant differences between correlation coefficients were established. The average width of stubs from which females emerge was greater than the average width of stubs from which males emerge. As a result there was a significant excess of females from large stems and a significant excess of males from small stems when the observed numbers emerging were compared with a theoretical 1 : 1 ratio.

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S. A. Wells, Cerealist, Cereal Breeding Laboratory, Lethbridge, while at Swift Current supervised the experiments and determined the sex, female length, and diameter of stubs from which male and female sawflies emerged. The assistance of A. W. Platt, former Officer-in-charge, Cereal Breeding Laboratory, Lethbridge, for his many suggestions and helpful criticism of the manuscript, is gratefully acknowledged.

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A SLIGHTLY MODIFIED FLUOROMETRIC METHOD OF TESTING FOR COUMARIN CONTENT IN SWEET CLOVER[1]

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A modification of Ufer's (6) fluorometric method of testing for coumarin was described by Slatensek and Washburn (2). The method outlined by the the latter authors is based on the principle that when leaf tissue containing coumarin is heated in a strong aqueous solution of sodium hydroxide the soluble sodium salt of coumaric acid is formed. When exposed to ultra-violet light this salt fluoresces green. The intensity of the green fluorescence measures the coumarin content of the leaf material. In the absence of coumarin the chlorophyll fluoresces a dull red. Slatensek and Washburn (2) demonstrated that by the fluorometric method the Pioneer variety (5) contained considerable coumarin, whereas by the colourimetric method of Clayton and Larmour (1) this variety was free of or very low in coumarin. This disagreement between the two methods also has been shown in unpublished work at the Dominion Forage Crops Laboratory. Because of the failure of the colourimetric method to detect certain forms of coumarin, the fluorometric method has been substituted for the colourimetric in testing for coumarin content at Saskatoon.

Slatensek and Washburn (2) described a rapid procedure of testing. Their general procedure for obtaining the sodium salt of coumaric acid required the use of 100 mg. of air-dried leaves and 15 ml. of 2.5 N sodium hydroxide per sample tested. After heating for 2.25 hours at 95° C., a small amount of the supernatant liquid was poured into one of the depressions in a spot plate and then exposed under an ultra-violet light.

When testing the coumarin content of a large population of plants a large total volume of the reagent was required. Furthermore, the transfer from the test-tube to spot plates required care in handling the highly caustic solution. With the object of reducing volume of reagent, of eliminating the transfer from the test-tube and of shortening the time required, some experimenting was done with modifications of the Slatensek and Washburn procedure.

MODIFIED PROCEDURE

The procedure finally adopted is to weigh out 20 mg. of air-dried and crushed leaves; add 3 ml. of 2.5 N NaOH and heat in a water bath at 95° C. for 1.5 hours. The test-tubes containing the solution are then exposed to ultra-violet light in a dark room. Comparative tests showed that this procedure was essentially as reliable as that involving considerably larger volumes and elimination of transfer speeded up the testing considerably. An operator can complete the test on 100 to 120 samples per 8-hour day.

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[3] Assistant Superintendent, Dominion Experimental Station, Prince George, B.C., and formerly in charge of clover investigations at the Dominion Forage Crops Laboratory.

[4] Head, Plant Chemistry Unit, Division of Chemistry, Ottawa.

A satisfactory method of preparing standards for visual comparison with the unknowns has not been developed. The procedure followed has been to score the samples visually on a basis of 1 to 5, where 1 is coumarin free and 5 is high in coumarin. Nine categories were obtained by means of sub-classes designated "+"; viz. 1, 1+, 2, 2+, etc.

An attempt was made to eliminate the time-consuming drying and weighing by cutting discs from the green leaves. Considerable variation was found in the weight of samples consisting of a definite number of leaf discs. Furthermore, no equipment was found which could be conveniently used to cut rapidly several discs from each plant. Consequently, weighing of the air-dried leaves has been followed as a routine procedure.

RELIABILITY OF RAPID TESTS

Sufficient leaves were collected from 103 plants to enable a coumarin determination to be made by both the rapid method and with a photofluorometer. The results of the two tests are presented in the form of a correlation surface in Table 1.

The wide range of coumarin content shown in Table 1 for the class scoring 2 on the rapid test was found also in another population of plants which were tested by the rapid test in the fall of their first year and by the photofluorometric method in the spring of their second year. Among the plants scoring from 3 to 5 there was at best only a slight relationship between the score and actual coumarin content. In the 3 and 3+ classes in particular there was a failure to distinguish between moderately low and moderately high coumarin plants. There was a tendency to underscore in these middle classes.

The tendency shown in Table 1 to underscore in the rapid test and not to differentiate clearly may have been due partially to the fact that included in this particular test were some plants with exceptionally high coumarin content. These particular plants belonged to the species *M. indica* and were scored 5. They thus set the upper limit in the scoring. When these

TABLE 1.—CORRELATION SURFACE FOR COUMARIN CONTENT DETERMINED BY PHOTOFLUOROMETRIC TEST AND COUMARIN SCORE BASED ON RAPID TEST.

Coumarin Percentage—Fluorometric Test	1	1+	2	2+	3	3+	4	4+	5
1.20						1	1		
1.10–1.19					1				
1.00–1.09							1	2	1
.90– .99				1				2	
.80– .89					1	2	3	1	
.70– .79					1	1	2	3	2
.60– .69					1		1	2	
.50– .59			1		1	1	2	3	
.40– .49			1		2	1		1	
.30– .39					3				(1)
.20– .29			1		1	(1)			(1)
.10– .19			4	3	6	(1)	1		
T.*– .09	2		1	1					
0.00	19	9	5						
Coumarin Score—Rapid Test									

* Trace.

plants were checked by the photofluorometric method their coumarin content ranged from 2.29 to 3.00 per cent thus being 1.5 to 2 or more times the coumarin content of high coumarin *M. alba* plants.

In breeding for free or very low coumarin content it is obvious from Table 1 that plants testing 1 or 1+ on the rapid test can be used with confidence in the breeding program. If types desirable in other respects were found among the 2 and possible 2+ classes these plants should be checked by the photofluorometric method before being used in the breeding program.

In the fall of 1949, from a large population tested by the rapid method, a few plants scoring 1 and 1+ were brought into the greenhouse and selfed during the winter. These plants were checked by the photofluorometric method. Their selfed progenies were set out in the spring of 1950 and coumarin determinations run on these progenies by both the rapid and photofluorometric methods. These selfed progenies were found to be breeding true for scores of 1 and 1+ and the photofluorometric test showed them to be free or at most to contain a trace of coumarin. It is of interest to record that rabbits fed on these low-coumarin progenies to such an extent that 80 to 90 per cent of the plants were killed. Adjacent rows of high to moderately high coumarin material were not eaten by the rabbits.

It should be noted that all the coumarin-free and low-coumarin plants listed in Table 1 and others being worked with at Saskatoon are derivatives of a cross between *M. alba* and *M. dentata* made by W. K. Smith of Madison, Wisconsin. The history and details of procedures used in securing this cross have been recorded by Smith (3), (4). He generously furnished a few seeds of the cross and all present low coumarin material in the project at Saskatoon traces back to these few seeds.

SUMMARY

A modification of Slatensek and Washburn's fluorometric test for coumarin content is described. The modification consists in reducing to one-fifth the amount of leaf material and reagent required and of eliminating the necessity of taking an aliquot.

Data are presented showing that the modified test clearly differentiates between very low coumarin or coumarin-free plants and those which are moderately high to high in coumarin content. The test is not as reliable in the medium to high coumarin levels.

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PRE-HARVEST CHEMICAL TOP KILLING OF LEGUME SEED CROPS[1]

II. GENERAL EFFECTS OF CYANAMID* COMPOUNDS

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INTRODUCTION

The use of petroleum oil for top-killing of legume seed crops as an alternative to swathing or natural freeze-drying in preparation for combine-harvesting has been discussed in an earlier report (1). The present paper deals with the use of cyanamid products for the same purpose. Progress of further studies to compare sodium cyanamid with aromatic oil and dinitro formulations used as top-killers in concurrent trials with flax and alfalfa is reported elsewhere (2).

MATERIALS AND METHODS

Contact herbicides used in triplicated square-rod plots and 0.1 to 4-acre field scale experiments performed in 1948, 1949 and 1950, at the University of Alberta and in neighbouring areas, were applied as sprays or as dusts from hand- or power-operated equipment. Well established stands of alfalfa and red clover were treated in 1948 and alfalfa and alsike clover in 1949 and 1950. In addition to these major trials, plots of birds-foot trefoil (*Lotus corniculatus*) were treated in 1950 to study efficiency of top-killing and more particularly the possibility of delaying pod-dehiscence. Normally the ready shattering of trefoil pods causes excessive seed losses.

Chemical sprays of potassium cyanate (Manufacturer's Code No. X1) and of sodium cyanamid (X5), were applied at various rates from 2½ to 60 pounds of X1 or 30 to 120 pounds of X5 in 40 to 400 gallons water per acre. Additives—soap, casein and several commercial household detergent powders—were evaluated in some of the experiments. They were incorporated at rates of 160 to 320 grams per 40-gallon solution.

Dry preparations of potassium cyanate (X1), sodium cyanamid (X10), calcium cyanamid and monosodium cyanamid were applied at rates ranging from 40 to 200 pounds per acre in certain of the comparisons with spray treatments.

Following application of the chemicals, observations were recorded with regard to rapidity and extent of response to the various dry and spray preparations. Some of the treated areas were harvested with farm machinery. Seed yield determinations were made where practicable and germination tests performed on samples from treated and control material. Later comparisons included inspection of root crowns and regrowth of parent plants in chemically-treated and in swathed areas.

Chemical analyses to determine carbohydrate, protein and phosphorus content of representative samples of root material taken at different times after plant treatment were also carried out but are not discussed in the present paper.

* Trade name for products of American Cyanamid Co.

[1] Contribution from the Department of Plant Science, University of Alberta, Edmonton. Adapted for publication from a thesis presented to the Graduate School of the University of Alberta by G. S. Cooper in partial fulfilment of the requirements for the degree of Master of Science.

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TABLE 1.—SUMMARY OF REPRESENTATIVE DATA SHOWING THE TOP-KILLING EFFECT OF VARIOUS CHEMICALS APPLIED AS PRE-HARVEST TREATMENTS TO DIFFERENT LEGUME CROPS GROWN FOR SEED

Treatment	Application rate per acre			Year applied			Crop	Percentage top-killing		
	Dust	Spray	Spray volume	1948*	1949*	1950*		1948	1949	1950
	Pounds	Pounds chemical	Gallons							
Pot. cyanate (X1)	—	60	200	*	—	—	Alfalfa	100	—	—
Pot. cyanate	—	40	200	*	—	—	Alfalfa	80	—	—
Pot. cyanate + casein	—	40	200	*	—	—	Alfalfa	100	—	—
Pot. cyanate	—	25	40	—	*	*	Alfalfa	—	90	100
Pot. cyanate	—	15	40	—	—	*	Alfalfa	—	—	85
Pot. cyanate	—	10	40	—	*	*	Alfalfa	—	50	25
Pot. cyanate dust	75	—	—	—	—	*	Alfalfa	—	—	20
Pot. cyanate	—	25	40	—	*	—	Alsike	—	80	—
Pot. cyanate + detergent	—	25	40	—	*	—	Alsike	—	90	—
Pot. cyanate dust	100	—	—	—	*	—	Alsike	—	20	—
Pot. cyanate + detergent	—	12	40	—	*	*	Alsike	—	60	50
Pot. cyanate + detergent	—	12	60	—	—	*	Trefoil	—	—	100
Pot. cyanate + detergent	—	20	9	*	—	—	Red clover	90	—	—
Pot. cyanate dust	80	—	—	*	—	—	Red clover	10	—	—
Sod. cyanamid (X5)	—	60	40	*	*	*	Alfalfa	90	90	85
Sod. cyanamid + detergent	—	60	40	*	—	*	Alfalfa	95	—	100
Sod. cyanamid dust	100	—	—	*	—	—	Alfalfa	25	—	—
Sod. cyanamid	—	60	40	—	*	*	Alsike	—	80	75
Sod. cyanamid dust	60	—	—	—	*	—	Alsike	—	20	—
Sod. cyanamid	—	60	60	—	—	*	Trefoil	—	—	100
Sod. cyanamid dust	120	—	—	—	—	*	Trefoil	—	—	5
Sod. cyanamid	—	80	40	*	—	—	Red clover	100	—	—
Sod. cyanamid dust	40	—	—	*	—	—	Red clover	5	—	—
Calcium cyanamid	200	—	—	*	—	—	Alfalfa	10	—	—
Monosodium cyanamid	150	—	—	*	—	—	Alfalfa	10	—	—

RESULTS

A summary of data showing the percentage top-killing by some of the most effective treatments and their effects on seeds and plant regrowth appears in Tables 1 and 2.

TABLE 2.—EFFECTS OF PRE-HARVEST TREATMENTS WITH POTASSIUM CYANATE AND SODIUM CYANAMID ON SEEDS AND PLANT REGROWTH FROM ALFALFA, RED CLOVER AND ALSIKE CLOVER

Treatment	Rate of application pounds per acre	Seed appearance compared with check	Seed germination percentage			Regrowth appearance	Percentage crown killing
			1948	1949	1949		
			Alfalfa	Red clover	Alsike		
Check: swathed	0	—	86	91	92	Normal	0
Pot. cyanate spray	10	Normal	89	92	94	Normal	0
Pot. cyanate dust	120	Normal	90	92	93	Normal	0
Sod. cyanamid spray	60	Normal	87	89	90	Normal	0
Sod. cyanamid spray	100	Normal	89	91	92	Normal	0
Sod. cyanamid dust	120	Normal	87	90	92	Normal	0

Data from field scale harvesting methods are not extensive enough to warrant at present an evaluation of the relative merits of the various chemical treatments in regard to possible improvement of seed yields. The figures in Table 3 however are of some interest in this connection.

TABLE 3.—SEED YIELDS OF ALSIKE CLOVER THRESHED WITH COMBINE HARVESTER FOLLOWING DIFFERENT PRE-HARVEST TREATMENTS OF 4-ACRE BLOCKS, 1950

Swathing	Potassium cyanate	Sodium cyanamid	Natural freezing
392 lb.	471 lb.	498 lb.	406 lb.

DISCUSSION AND CONCLUSIONS

1. Of the "cyanamid" chemicals tested, potassium cyanate and sodium cyanamid were outstanding as top-killers when applied in spray form. Dusts were unsatisfactory.

2. Although smaller amounts of potassium cyanate were effective in comparison with sodium cyanamid the latter is somewhat more caustic, hence more rapid in action and in addition is likely to be cheaper commercially. Care to avoid skin irritation should be taken while handling this material and sprayers should be rinsed thoroughly after use.

3. While as little as 9 gallons spray solution per acre sometimes produced very good results, 40 gallons or more were generally required for adequate coverage and top-killing.

4. Better results were obtained when a wetting agent was added to the spray solution. In general there were only minor differences between the suitability of soap, casein, and a number of trade-name household detergents.

5. Major differences in results within a particular season were due to variation in height and density of stand of the crop, rather than to species tested.

6. Rates of application therefore should be adjusted in accordance with results from a preliminary trial made a few days in advance of the major operation in a given year. In general, however, 30-60 pounds sodium cyanamid, or 15-35 pounds potassium cyanate, with added detergent in 40 or more gallons solution per acre, appear to be the ranges of suitable rates for ground spray rigs in preparation for combining alsike, alfalfa or red clover within 5 days after treatment.

7. Preliminary trials have shown that complete top-killing is not essential for satisfactory combining. Drying out of about 80 per cent of the top-growth of alsike, alfalfa, and red clover permitted good threshing without appreciable mixture of the seed with shattered leaf and stem material.

8. Pre-harvest treatment of birdsfoot trefoil was effective in killing top-growth and in delaying by several days the dehiscence of seed pods, especially those immature at time of treatment. Additional experimentation is necessary to establish recommendations regarding this phase of the work.

9. As judged by the conditions of harvested seed, its germinability and the inspection of plant crowns and regrowth, there were no harmful effects from the use of the top-killers concerned.

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A SELF-PROPELLED HERBICIDE SPRAYER FOR EXPERIMENTAL PLOTS[1]

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Since treatment of experimental plots with herbicides has become common practice a suitable sprayer for this work has been sought.

Commercial machines were either too large or lacked some of the features which were thought necessary; consequently it was decided to build a machine to fit the requirements of field plot work. The first model was built in 1948-49. It has been redesigned twice since that time; and it is felt that the present machine meets the required objectives.

OBJECTIVES

The objectives were as follows:

(1) A self-propelled machine simple enough to be operated by one man and running on bicycle wheels to eliminate the crop damage caused by large tractor wheels in solidly sown plots such as elite or foundation stock.

(2) Uniform spray coverage.

(3) Steady rate of travel irrespective of irregularities of surface, with no tendency to over-run the drive.

(4) Short turning radius, drive through both wheels, a smooth acting clutch and maximum manoeuverability to minimize crop damage.

(5) A spray boom wide enough to cover fairly large areas in a reasonable time and capable of being reduced to a 3-foot width when required.

(6) A maximum weight not in excess of 150 lb., so that the machine can be readily handled, and small enough in size so that it can be transported on a two-wheeled trailer towed behind a car.

(7) A pressure-regulating system capable of maintaining uniform pressure irrespective of the number of spray sections in use, without readjustment and without excessive back-pressure on the pump.

DESCRIPTION OF THE MACHINE

The present machine is shown in Figure 1. The frame is built of $\frac{5}{8}$-inch and 1-inch steel tubing, the axle housing of $1\frac{1}{4}$-inch steel tubing with bronze bearings pressed into it to carry the $\frac{3}{4}$-inch cold rolled axle shafts. The $\frac{5}{8}$ H.P. Johnson engine and $\frac{1}{4}$-inch brass gear pump are mounted on slides made of $\frac{3}{4}$-inch angle iron, so that they each have fore-and-aft movement for belt adjustment. The drive is from the engine to the front countershaft by a single vee velt; from the front countershaft a single vee belt goes to the pump pulley and double vee belts to the rear countershaft. A sprocket on the rear countershaft drives the large axle sprocket by means

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of a short bicycle-chain. The large sprocket is used as a crown wheel on a simple differential through which the wheels are driven. The addition of this differential, which is easily and cheaply constructed, makes the handling of the machine very much simpler, and eliminates the tendency of the wheels to skid and damage plants or grass when making a turn. The front countershaft supports are pivoted to the frame so that the whole countershaft may be tipped backwards to loosen all 4 belts or pulled forward to tighten them by means of a hand lever mounted on the right steering handle as shown in Figures 2 and 3. This makes a very smooth acting clutch for the drive wheels and pump. When the machine is stopped the pump is not operating, so that the engine may be left running without damage to the pump. The over-all speed reduction from engine to drive wheels is 45:1.

The differential was built of 4 die cast washing machine bevel gears and 2 pieces of cold rolled steel at a cost of $4.00 for parts. Details of construction are shown in Figure 4. The spray boom is built of $\frac{5}{8}$-inch steel tubing with threaded brass blocks hard-soldered to it to take the spray nozzles and $\frac{1}{4}$-inch copper tubing and fittings which carry the fluid to the nozzles. The boom is in 3 sections—a centre section 38 inches long, and 2 hinged, outer sections each 50 inches long. The centre section has an upright 28 inches high welded to it. Light, closed-link furnace chain is attached to the top of this upright and to a point near the outer end of each folding section of spray boom. This serves to keep all 3 sections of the boom at a uniform height when in spraying position. A simple yoke-and-bolt arrangement allows the outer sections of boom to be folded back to a support on the upright when only the centre section is being used. Flexible hose connections at the joints permit the booms to be raised and lowered, and a shut-off cock at each end of the centre section cuts the fluid supply to the outer sections when desired. The boom is attached to two uprights projecting from the front of the frame, and a series of holes in the uprights allows the boom height to be varied at will. The spray nozzles are so placed that a uniform coverage is obtained when the nozzles are 20 inches above the level where the spray is required. Since the fluid delivery is constant the rate of application of herbicide is governed entirely by the concentration of chemical used.

The spray pressure is regulated by a $\frac{1}{4}$-inch diaphragm-type regulator and a ball relief valve. The relief valve is set for 50 pounds pressure, 10 pounds above the spraying pressure used. The pump output is much greater than is required to supply the spray nozzles and as a result the excess is bypassed by the relief valve through a tube leading to the bottom of the supply tank, serving to keep the fluid in the tank agitated. A 0-100 lb. pressure gauge is fitted as a check on spraying pressure. This system maintains a practically uniform pressure without any change in regulator setting, irrespective of the number of spray nozzles being used. It is necessary to use the relief valve to get this result; the regulator alone will not do it.

A filter on the inlet side of the pump was used on the first model but it was found to restrict the flow to the pump. Possibly a larger capacity filter would have been satisfactory but it was decided to use a filter on

FIGURE 1. Front view of machine, booms extended.

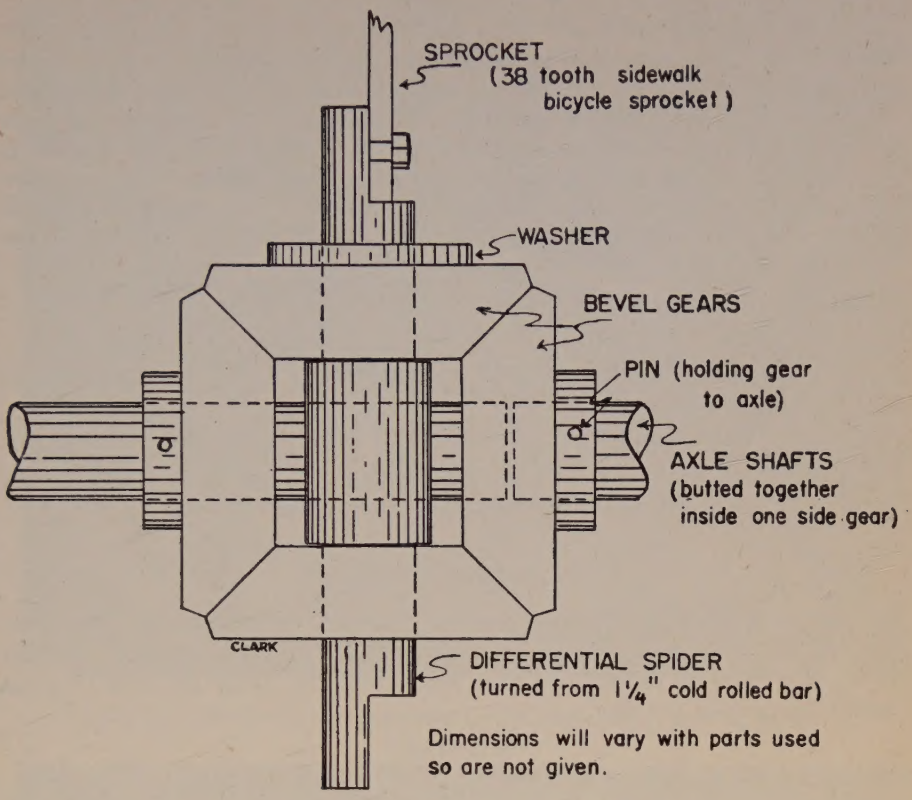

FIGURE 4. Details of differential construction.

the pressure side. An ordinary gasoline filter was tried but would not stand the pressure; so a brass filter body with a screw joint was made to take regular gas filter screens and gaskets. This works quite satisfactorily.

The spray jets used are "Tee jet" Number 650067, the same as those on the large commercial machines. They are spaced 20 inches apart on the boom, 2 on the centre section and 3 on each folding section. The total width covered by the boom is 13 feet.

The tank used on this machine is of brass and has a capacity of approximately 3½ Imperial gallons. It has an anti-splash rim and a cover 8 inches in diameter to allow for easy cleaning. A 5- or 6-gallon tank could be used to advantage, but this one was used because it was on hand.

A lever on the left handle raises and lowers a support on which the machine rests while starting the engine, filling the fluid tank, etc.

Grease nipples are fitted to axle and countershaft bearings.

The steering and supporting handles are adjustable for height so that the boom is kept at a uniform height above the ground when the handles are adjusted to suit the operator. The point of balance is slightly back of centre so that the handles rest comfortably in the operator's hands.

The machine is fitted with bicycle front wheels equipped with 26 × 2.125 inch tires (the widest standard bicycle balloon tire). The ball bearings were removed from the wheel hubs and the solid axle sewer turned to fit closely inside the hubs. Two notches were ground in the inside of each wheel hub and small pieces of steel welded to the axle to engage with the notches to prevent slippage. The wheels are held in place by nuts and washers on the threaded outer end of the axle plus a small spacer which fits over the axle and into the hub. The spacing of the wheels is fixed at 36 inches, centre to centre.

Vee pulley sizes are as follows:

Engine—2-inch diameter to 8-inch on front countershaft.

A pair of $2\frac{1}{2}$-inch on front countershaft to a pair of 8-inch on rear countershaft.

A $3\frac{1}{2}$-inch on front countershaft to a 2-inch on pump.

A 9-tooth sprocket on rear countershaft drives a 38-tooth crown sprocket on the differential by means of a short bicycle chain.

OTHER USES

Because of its light weight and easy manoeuverability this machine is well suited for spraying large lawns or golf-courses with herbicide. With a 6-gallon tank to reduce the time spent refilling, 15 or 20 acres of grass could be sprayed per day.

SUMMARY

A small self-propelled herbicide sprayer constructed to meet the requirements of experimental plot work is described. The machine weighs 135 lb. and is easily operated by one man. Several acres a day can be covered. Spraying pressure holds constant and coverage is uniform. It is easily transported in a small trailer. It will travel between rows or on pathways eliminating damage to plants.

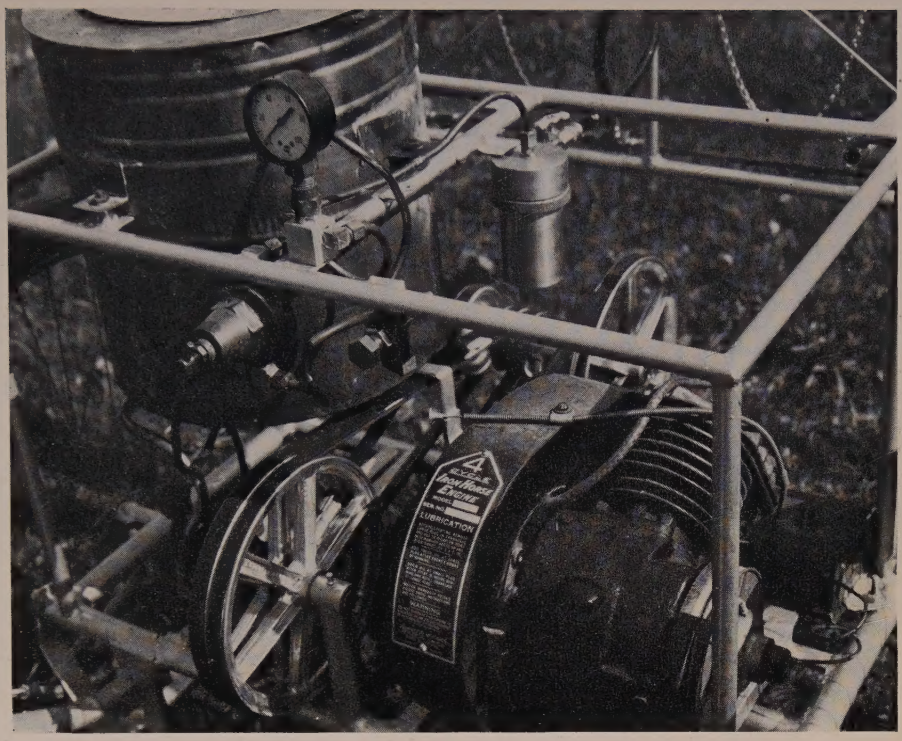

FIGURE 2. Location of rear countershaft, relief valve, filter, pressure gauge, etc.

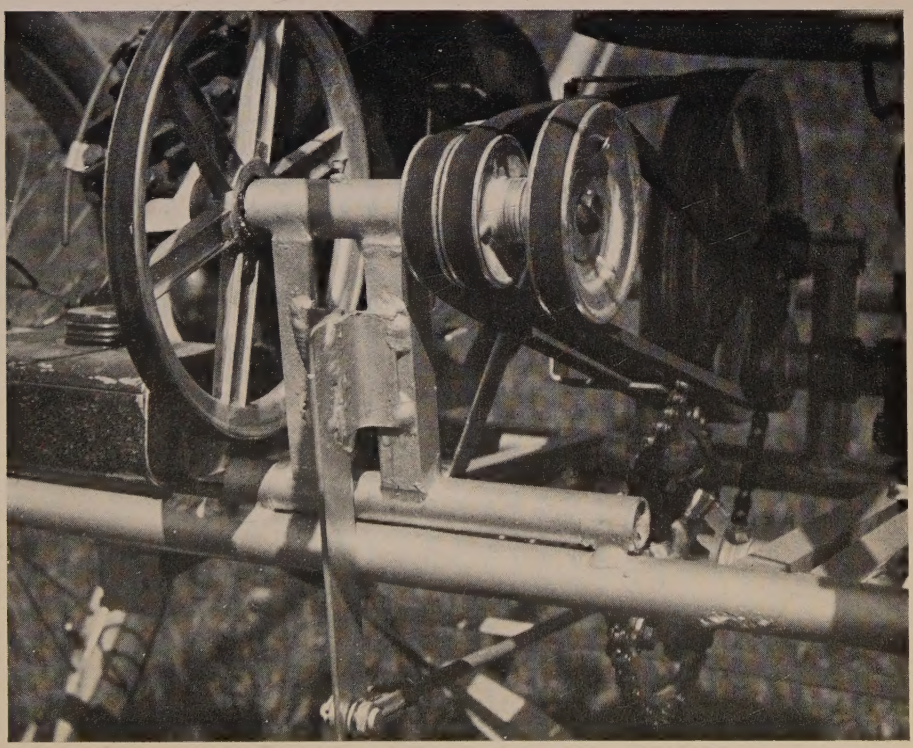

FIGURE 3. Front countershaft and rocker assembly to tighten all four belts.